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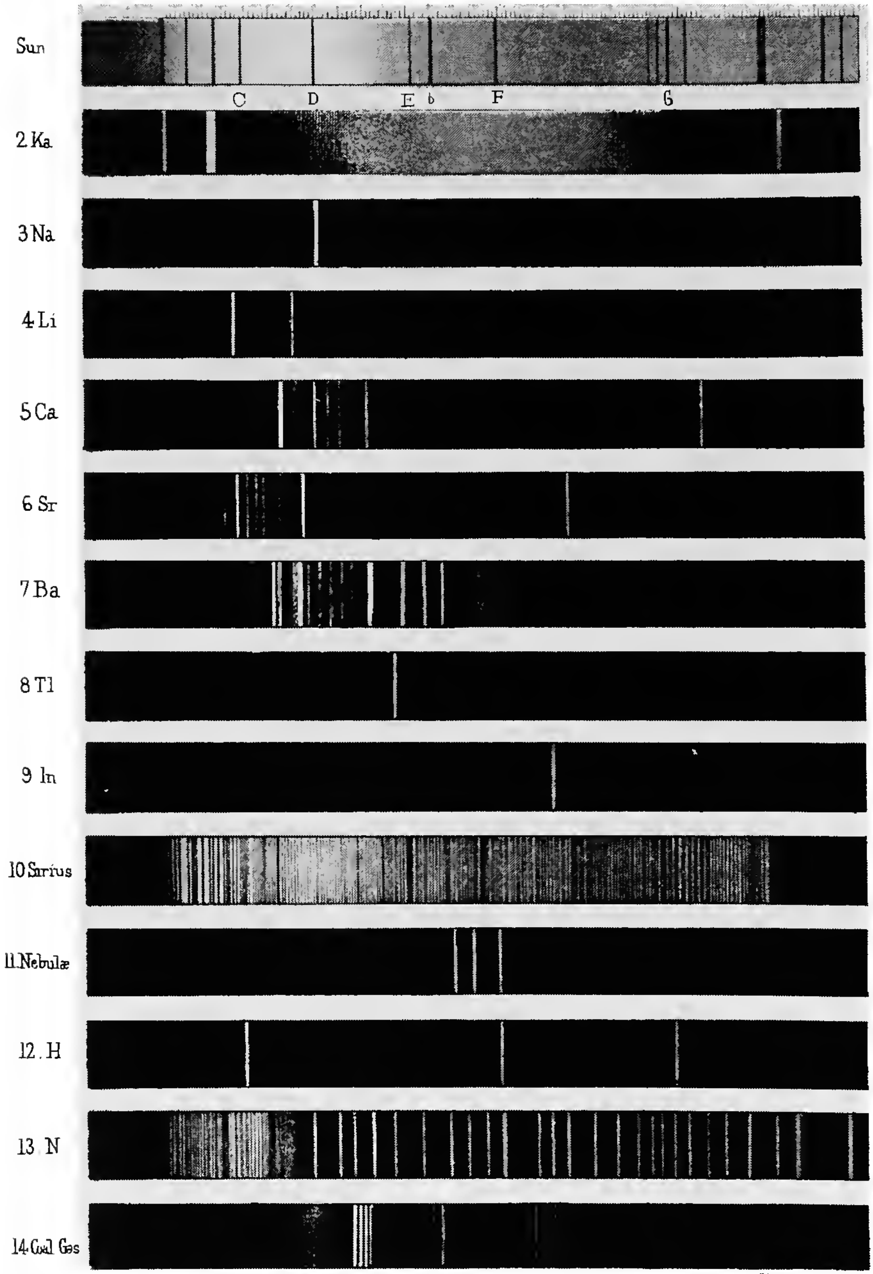

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ASTRONOMY

BY

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TRANSLATED BY C. B. PITMAN.

WITH NUMEROUS ILLUSTRATIONS.

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PREFACE.

THE late Father Gratry, Member of the French Academy, once said: "It is astonishing how ignorant the great bulk of the public are in regard to astronomy. I have known men of education maintain that the ancient system of astronomy (which they considered to be the most philosophical, and branded me as an empiric for not agreeing with them) was the true one; that the sun revolved round the earth, not the earth round the sun.

"Thus is it that this science, so simple, easy, regular, luminous, majestic and religious, so full, in all its details of the deepest interest, a model of all other sciences and a masterpiece of human intelligence has not only failed to become popular, but is even unknown to the great majority of those who have received a liberal education. It is true that the fault mainly lies in the defective manner of its teaching." *

These remarks are, unfortunately, borne out by experience, and therefore justify me in adding another

* See Father Gratry's *Sources*, Part i., p. 136.

to the list of publications, many of them very excellent ones, which have been put forth with the view of popularising this science. It, of all others, inspires the most grandiose ideas, calculated at once to elevate the mind and develop the intelligence; it is also, as I believe, one of the branches of human knowledge, the principles of which can be the most easily comprehended when they are expounded in clear and simple language, divested, that is to say, of technical terms.

This volume has long been in preparation. So early as 1852 I pointed out in an influential newspaper the progress of science, and in the columns of *La Science pour tous*, of which I was editor-in-chief for several years, the successive discoveries of the astronomers were carefully registered. In 1865 I published an elementary treatise, which had an exceptionally large circulation, and since then, a more complete work, which was adopted by the official committee of the Ministry of Public Instruction.*

* It was in reference to this publication that M. Babinet, of the Institute, wrote me the following lines :—

"My dear Rambosson :

"I have read your work on *Astronomy* with much interest, and have satisfied myself that the clearness of the language has not prevented it from being scientifically exact. I have in particular noticed that you have set forth the most recent advances in Astronomy, so as to bring them within the reach of ordinary intelligence, &c.

"Ever yours,

"Paris, *March* 8, 1866. "Babinet, of the Institute."

My final task is therefore facilitated, as my functions and inclination have led me to note each new fact as it appears, and these will be found chronicled in the following pages. I have also made a conscientious compendium of the most advanced and best authenticated theories, to which I have adjoined my own personal observations.

My labour, too, has been materially lightened by the house, or rather dynasty, which has undertaken the publication of this work; and I have also to thank the artists who have supplied me with the illustrations, which will be found of unusual excellence. It only remains for me to express a hope that the public to whom I address myself will find this book worthy of their notice.

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ASTRONOMY.

CHAPTER I.

ORIGIN AND PROGRESS OF ASTRONOMY.

Origin of Astronomy — Antediluvian traditions — Astronomy amongst the Indians—Astronomy amongst the Chinese—The Emperor Chun's Sphere —The astronomers *Hi* and *Ho* put to Death for having neglected their duty—A remarkable Antique Text—Astronomy amongst the Chaldæans —Abraham as an Astronomer—The Book of Job—Astronomy 2000 years before our Era—Ancient collection of Observations taken at Babylon —The Egyptians and Astrology—The circular Zodiac of Denderah—The great Pyramid of Gizeh, from an Astronomical point of view — The Ptolemys, Kings of Egypt, Patrons of Sciences and Letters—Thales, Anaximander, Anaxagoras, Pythagoras, Pytheas, Aristarchus, Aristotle, Hipparchus, and his Catalogue of 1022 Stars—Julius Cæsar, Sosigenes the astronomer, and the learned Achoræus—Pompey and the gifted observer of silent Olympus—Ptolemy and his School—The Arabs and Almagestes—Copernicus, his System, his Apprehensions, and his Swan-like Song before Death—Galileo's exclamation: "Oh! Nicholas Copernicus!" — Tycho-Brahé and his System — Uranienburg — Descartes, Philosopher and Savant—Newton and his splendid Discoveries.

I.

Astronomy, as indicated by its Greek derivation (*αστήρ*, star, *νομος*, law), is the science of the motions of celestial bodies. The purely descriptive part is often designated by the names of *Uranography* and *Cosmography*. Its origin amongst all nations is lost in antiquity; and this may be readily understood, for the first impulse of man must naturally be to observe the sky, the rising and setting of the stars, their respective and varying positions, their relation to the seasons, their diverse influences, &c.

Thus Bailly retraces the origin of this science to certain antediluvian traditions, saved out of the general wreck; and Josephus, in his Jewish Chronicles, cites, as an instance of the attraction which the phenomena of the firmament possessed for the Patriarchs, the *débris* of a column which he states to have been still extant in his time in Syria, and upon which the descendants of Seth, third son of Adam and Eve, had engraved, several centuries before the deluge, the leading results of their observations.

"The spectacle of the firmament must," says Laplace, "have taken the attention of primitive man, especially in countries where the serenity of the air lent to the observation of the stars. In the pursuit of agriculture, he must have needed to know the various seasons, and to be able to prognosticate their recurrence. He would soon have discovered that the rising and setting of the principal stars at the moment of their plunging within the solar rays, or of their emerging therefrom, facilitated him in his purpose. Thus it is that we find the traces of astronomical observations dating back to such a remote period in the history of every nation."

India, the earliest civilized part of the Old World, presents a subject of study replete with interest for any one who will give it his special attention; and though I do not pretend to possess any great knowledge of Hindoo astronomy, it is impossible to doubt that this people was deeply versed in this science, which was specially cultivated by the guardians of the holy places. Cassini, Bailly, and Playfair are of opinion that the Hindoos have transmitted to us observations taken more than 3000 B.C., and though this date is contested by other eminent *savants*, they all admit the great antiquity of the documents in which these observations are comprised. Benthey, the most ardent adversary of the

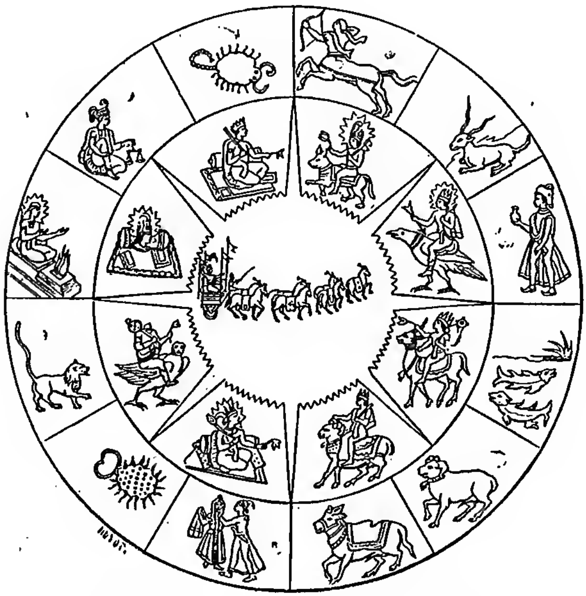

Fig. 1.—Zodiac and solar systems of the Hindoos.

Hindoo pretensions, himself admits that their division of the ecliptic into twenty-seven lunar stations must have been made in the year 1142 of our era; and this division could only have been the result of a vast number of observations extending over an immense period. The astronomical law laid down by the Vedas for the arrangement of the calendar must necessarily date back to the fourteenth century before Christ, and Parasara, the first known Hindoo author who wrote on astronomy, probably lived about the same time.

It seems astonishing that the Hindoos, well versed as they were in science generally, should have been so ignorant in matters relating to our globe. Fig. 2 represents Mount Meroo, which, as they believed, formed the centre of the world. It was said to be a conical-shaped mountain, and its sides to be covered with precious stones, its summit

Fig. 2.—The seven regions of the upper world, according to the Hindoo tradition

being a sort of terrestrial paradise. This idea may have been inspired by the sight of the lofty mountains which ran along the northern frontier of India; but, for all that, Mount Meroo has no existence save in the imagination of the Hindoo mythologists. They supposed it to be surrounded by seven concentric belts of habitable lands, divided from each other by seven oceans. The central belt was said to comprise India, and to be surrounded by a salt-water sea; the other belts being separated from each other by seas of milk, wine, molasses,* &c. In contrast to these errors, we find in the astronomical writings of the Hindoos the proofs of a truly wonderful amount of learning.

II.

To the Chinese we owe the earliest information upon astronomy which has any claim to exactitude. From time immemorial they have celebrated the epoch of the solstice, in the hope of seducing the sun, by their dances and festivities, to delay his departure towards the equinoxes; and, though the first eclipses to which their annals allude are only vaguely mentioned, they prove nevertheless that in the time of the Emperor Yao, 2000 B.C., astronomy was made the subject of special study. When Yao, whose reign had been entirely devoted to the welfare of his subjects, died, at the age of 118, they wore mourning for him during a space of three years. "On the first day of spring (2255 B.C.) Chun was installed as heir of the emperor in the hall of his ancestors. Examining the *instrument decorated with precious stones which represents the stars* and the *movable tube which enables one to observe them*, he regarded the seven planets. This done, he offered sacrifice to the Supreme Lord of Heaven, and went through the usual ceremonies in honour of the six great spirits, as well as those usually performed in respect of the mountains, the rivers, and the spirits generally."†

This instrument, *representing the stars*, was a sphere of the heavens, termed Sicoun-Ki. The likeness of it is preserved by the Chinese in several editions of the *Chou-King*,

* *India*, by MM. Dubois de Jancigny and X. Raymond.
† *Chou-King*, chapter 2.

and is accurately reproduced in Fig. 3. This sphere represents the vault of the firmament divided into sections,

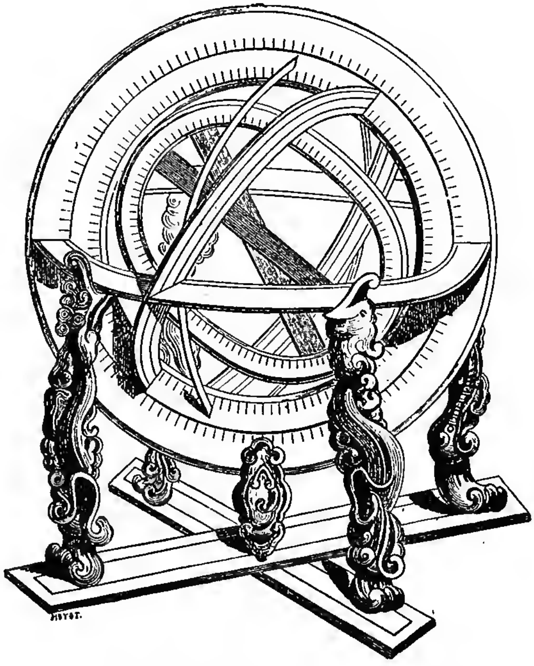

Fig. 3.—The Emperor Chun's sphere.

with the earth in the centre, and the sun, the moon, the planets, and the stars in the places assigned to them in the Ptolemæan system. If this sphere is really authentic, it proves a high degree of astronomical knowledge for so remote an epoch.*

The Chinese were acquainted with the use of the dial; they measured time by the aid of the clepsydra. They

* Pauthier's *Histoire de la Chine* (Firmin-Didot).

constructed instruments for measuring the angular distances of the stars, and ascertained that the solar year, which they made begin with the winter solstice, was about six hours longer than 365 days. Their civil year was lunar, and, to bring it back to the solar year, they used the period of nineteen solar years, which is equal to 235 *lunations*—a period exactly equivalent to that which Callippus, sixteen centuries later, introduced into the Greek calendar. They also divided the equator into twelve immovable signs and twenty-eight constellations, in which they carefully assigned the position of the solstices.

III.

Their estimates have been confirmed in the cases of thirty-one out of the thirty-six eclipses, the elements of which have been handed down to us, and which they state to have been observed between the years 776—480 B.C.

The Chou-King alludes to an eclipse of the sun which occurred in the reign of Tchoung-King, who, in connection with it, put to death *Hi* and *Ho*, two functionaries who were at once astronomers and directors of religious ceremonies. They were accused of preferring the pleasures of the table to the observance of their astronomical duties, and it is interesting to cite the Chinese text bearing upon this matter:—"At that time, *Hi* and *Ho*, abandoning themselves to vice, neglected their duties; they besotted themselves with wine; they neglected the duties of their office, and degraded themselves from their rank; they created confusion in the *celestial chain*, and left their functions unfulfilled. Upon the first day of the third moon of autumn, the Tchin (a conjunction of stars) was not in harmony with the constellation Fang (Scorpio). The blind man sounded the drum (the drummer was always a blind man); the magistrates and people assembled in haste, like a horse let loose. *Hi* and *Ho* were like slaves at work, they neither heard nor saw anything. Having become unable to distinguish the celestial signs and appearances, they incurred the penalty decreed by the kings our predecessors. The *Tchingtien* says: 'Whoso advances the march of time shall be put to death; whoso retards it shall also be put to death.'" *

Father Gaubil, in his "History of Chinese Astronomy," fixes the date of this eclipse as far back as 2155 B.C.

In China an eclipse of the sun has always been looked upon as a matter of importance to the State. Upon the occasion referred to, the mandarins, when the sun was suddenly veiled from their eyes, were obliged to repair in hot haste to the palace, and to provide themselves with bows and arrows to protect the emperor, who is looked upon as the image of the sun. The bandmaster, who was a blind man, sounded the drum, the mandarins offered presents in honour of the spirit, whilst the emperor and court grandees put on plain apparel, and remained fasting. The nature of the laws edicted by the early kings against the calculators who made a mistake in their observations indicates the great antiquity of Chinese astronomy. It is also worthy of notice that when the Chinese astronomers were merely culpable of slight negligence, or a trifling miscalculation, they were not visited with a heavier punishment than that of fine, reprimand, or dismissal. The punishment of death was reserved for other misdeeds committed by the astronomer-in-chief. †

* Pauthier's *Histoire de la Chine*, pp. 58 and following (Firmin-Didot).

† Father Gaubil's *Histoire de l'Astronomie Chinoise.*

IV.

The Chaldæans come next, some of their observations being said to date back to nine centuries before Alexander the Great. When that monarch made his victorious entry into Babylon in 331 B.C., some of the astronomers presented him with a series of observations extending over 1903 years, and dating back to the time of Nimrod. Calisthenes, who accompanied the Macedonian, sent them by his order to Aristotle. The latter tells that some observations still more ancient were lost, and he mentions a circumference of the earth, the measure of which relates to the climate of Tartary; but he does not say how or by whom it had been calculated, while the annals of China explain the operation without giving the result.

Periods, which it must have taken centuries of observation to discover and calculate, were in use amongst the Chaldæans. They were acquainted with the ancient planets; they possessed a zodiac divided into twelve constellations, and a sphere which has served as a model to our own; they were also able to predict eclipses. Ptolemy testifies that they had, from the most remote ages, been in the habit of observing the occultation of stars by the moon, and that they were familiar with usage of sun-dials. They knew, too, the celebrated period called *Saros*, adopted by the Greeks, which includes about 18 solar years, 15 days, and 10 hours. The recurrence of this period had the effect of bringing the return of the eclipses upon the same day and in the same order as in the preceding period. It is the cycle which Meton revealed to the Greeks, and the calculations of which the Athenians caused to be engraved in letters of gold. Bailly asserts that this period was taught to the Chaldæans by a more ancient race; and it is remarkable that the same period was known to the Chinese, the Hindoos, and other peoples being far apart, and, to all appearances, holding no communication with each other. Yet, if we are to believe the great majority of historians, the fertile plains of the Tigris and Euphrates were the cradle of astronomy.

Abraham, born at Ur of the Chaldees, about 2040 B.C., is the starting-point of Jewish history; he knew the true God, and led a holy life. The great Patriarch was always famous in the East; the Chaldæans, his compatriots, considered him as one of their most eminent astronomers.

Need I cite that magnificent passage in the Book of Job?

"Canst thou bind the sweet influences of the Pleiades, or loose the bands of Orion?

"Canst thou bring forth Mazzaroth in his season? or canst thou guide Arcturus with his sons?

"Knowest thou the ordinances of heaven? canst thou set the dominion thereof in the earth?

"Canst thou lift up thy voice to the clouds, that abundance of waters may cover thee?

"Canst thou send lightnings that they may go, and say unto thee, Here we *are*?

"Who hath put wisdom in the inward parts? or who hath given understanding to the heart?" *

It is believed that Job inhabited Arabia, not far from the borders of Chaldæa, in the eighteenth century before our era.

M. Elie de Beaumont says:—"The first astronomical observations are lost in antiquity. The Chaldæans were possessed of certain notions, by no means inaccurate, as to the stars, and the laws to which their movements are subjected. For the last three thousand years astronomical observations have been accumulating in enormous pro-

* Book of Job, chapter xxxviii. verses 31—36.

portions, and becoming more precise. Tables of the results attained have been compiled, each more perfect than the preceding one, so that it is now possible to predict with certainty what position each of the stars in the solar system will occupy at a given moment. They supply the materials for calendars and almanacs, the infallibility of which has become proverbial."*

The knowledge of astronomy soon spread from Chaldæa into Phœnicia and Egypt. The observations taken by the Egyptians of the motion round the sun of the planets which we call Mercury and Venus, proves how successful they were in this direction, and their priests were more particularly renowned; but under the name of *astrology,* they made the movement of the stars to bear upon the various events of life, and so claimed to foretell the future. Thus it was in the sanctuary for the most part that the exact sciences were studied and perfected, and their results made to serve some purpose of general usefulness. The astronomers were brought up to the priesthood, and the vast platforms (or flat roofs) of the temples were useful as observatories. Their observations in time taught them that the rising of the same stars ceased, after the lapse of several centuries, to correspond to the same seasons, and they noticed their change of position. They divided the heavens into constellations, the names and figures of which were taken from Egyptian subjects. They constructed a zodiac which is thought to have been in existence earlier than 2500 B.C. The civil calendar was arranged, the year being composed of 365 days, which were divided into twelve months, each of thirty days, and

* Elie de Beaumont's *Eloge Historique de Jean Plana,* read before the Académie des Sciences, November 25th, 1872.

followed by five supplementary days. They also made use of the week, or period of seven days.*

V.

Astrology, as I have remarked, was in vogue amongst the Egyptians, as is to be proved from the zodiacs which have been handed down to us. Fig. 4 is a miniature engraving of the circular zodiac of Denderah.† At first sight it seems to be nothing more than a conglomeration of various figures surrounded with sacred letters; but on closer inspection we notice an outer circle, with an inscription traced in sacred letters, and intersected at equal distances by figures with the head of a woman looking upwards, or that of a hawk in a reclining posture. These figures, their arms raised aloft, hold up a shield entirely covered with signs of various kinds. To the left, a little below the centre of this shield, which represents the firmament, is seen a lion, followed by a woman and treading upon a serpent—this is the zodiacal sign of *Leo*. Behind this group is a woman holding in her hand a wheat-ear—this is *Virgo*. We then notice, going from the right to left, *Libra* with its two scales; *Scorpio, Sagittarius*, in the shape of a winged centaur; *Capricorn*, half goat half fish; *Aquarius*, pouring water out of two vessels; the *Pisces*, connected with each other by triangular lines; next to them *Aries, Taurus*, and the *Gemini*, which represent two men walking in company; and, in succession, *Cancer* just above the head of the Lion. *Leo* is the first sign in this system of the zodiac; within and beyond the spiral line formed by the twelve signs, come the chief extra-zodiacal constellations, and as the gigantic animal, moving on its hind legs near the

* *Egypte*, by Champollion-Figeac, p. 95.
† See *Recherches sur l'Egypte*, by Latronne.

centre of the disc, has been generally admitted to represent what we know as Ursa Major, the North Pole must be placed in close proximity to this figure. The discovery of the Denderah and Esnah zodiacs * led to very fierce discussions, which, however, need not be referred to in these pages.

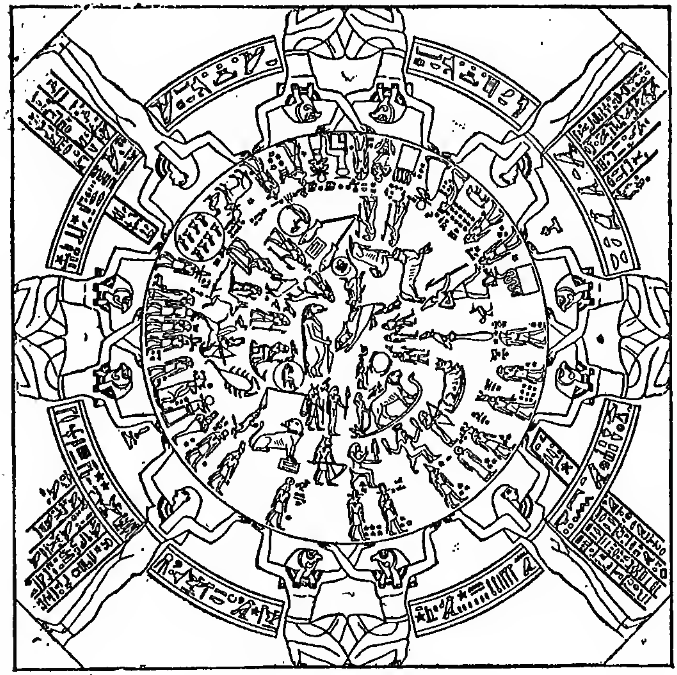

Fig. 4.—The Circular Zodiac of Denderah.

The pyramids are very remarkable from an astronomical point of view; they represent the most ancient monument of human skill in the known world. The largest, that of Gizeh, is the most carefully constructed, being so built that each of its four corners faces exactly one of the four cardinal points. Even in the present day we should find it difficult to trace so vast a meridian without deviating a

* See *Recherches sur l'Egypte*, by Latronne, p. 14.

single fraction. From this situation of the great pyramid has been drawn the conclusion, very important as bearing on the physical history of the globe, that the position of the earth's axis cannot have varied to any perceptible extent for thousands of years. It may be added that the great pyramid is the only monument in the world which, from its antiquity, is capable of supplying the means for ascertaining such a fact. The appended illustration, after Champollion, represents the present appearance of this pyramid and of the Sphynx, which stands in close proximity to it.

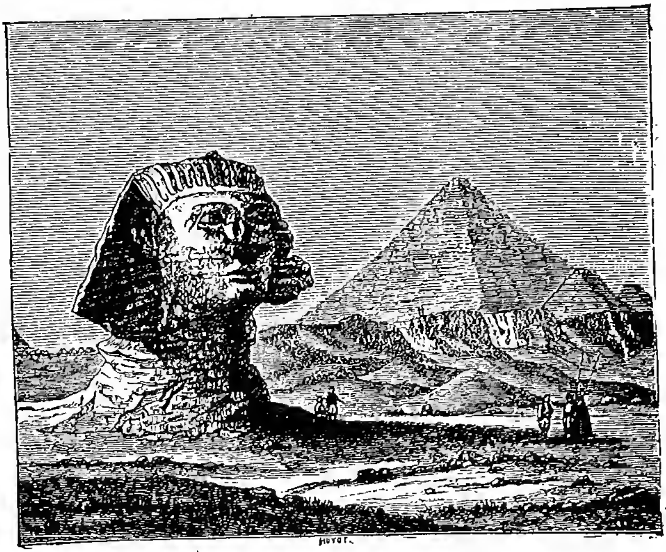

Fig. 5.—The great Pyramid of Gizeh and the Sphynx

The encouragement offered by the Ptolemys—more especially by Ptolemy Philadelphus—to science and art, gave a great impluse to the development of intellectual knowledge. We know that the latter king attracted to his capital the most learned men in Greece, that he lodged them in his palace, and furnished them with every facility for carrying out their scientific studies and researches.

VI.

The Greeks did not cultivate astronomy until long after the Egyptians, whose pupils they were. In the year 640 B.C. Thales of Miletus went to Egypt to study, and he afterwards founded the Ionian school, in which he taught the spherical shape of the earth, the obliquity of the ecliptic, and the causes which superinduce eclipses of the sun and of the moon. After him came Anaximander and Anaxagoras, to the first of whom is credited the invention of the dial, the terrestrial globe, and geographical charts. Soon after, this school produced Pythagoras of Samos, a pupil of Thales, who made several journeys to Egypt and India. On his return home he was driven into exile, and went to Italy, then called Greece Major, where he founded the school named after him. In addition to the subjects taught by the Ionian school, he expounded the two distinct motions of the earth, one upon its own axis and another round the sun. He asserted that the stars were suns, the centres of so many planetary systems. Thus we see that the fundamental principles of the astronomical system now universally accepted were in general use five hundred years before the birth of Christ.

From the time of Pythagoras it was maintained that the regular movement of the celestial bodies through space produced an ineffable harmony which was termed the harmony of the spheres. In the first place, the *aspects* were held to have an affinity with the intervals of the tones. Thus, the quadrate aspect, or the quadrature, is, as compared to the sextile aspect, or 60 degrees, as 3 is to 2—this is the affinity which forms the fifth (*quinte*) in music. Kepler himself endeavoured to establish a relation between the distances of the planets from each other and the intervals of music; but these comparisons are very arbitrary and incomplete. In proportion as the theory of music has been made more perfect, the ideas formed as to this harmony have undergone great modifications. It was supposed that the moon, as the lowest of the planets, that is, the nearest to us, answered to the note *mi*, Mercury to *fa*, Venus to *sol*, the Sun to *la*, Jupiter to *ut*, Saturn to *re*; and the orbit of the fixed stars, as being the most distant (or highest) of all, to *mi* or to the octave.

The most celebrated astronomers, after Pythagoras, were Pytheas, who taught the way to classify climates by the length of the days and nights; Aristarchus of Samos, who fixed the apparent diameter of the sun in the year 281 B.C., and calculated the distance of that planet from the earth; and, thirdly, Aristotle, the disciple of Plato, who set himself to ascertain, by a series of astronomical observations, the shape and size of our planet.

They were followed by Hipparchus of Bithynia, who achieved great renown in the celebrated school of Alexandria 140 years B.C. This great astronomer, looking upon previous researches as unreliable, determined to go over the whole ground afresh, and to admit as genuine only those which should be confirmed by his own experience. He fixed to a nicety the extent of the tropical year, discovered the precession of the equinoxes, and it is to him that we owe the use of latitudes and longitudes. A new star having suddenly appeared, he composed a catalogue of 1022 different stars, which he calculated for the 128th year before the Christian era. This Pliny terms "an enterprise worthy of the gods, for Hipparchus thus afforded the means for ascertaining hereafter whether certain stars disappeared, and whether they underwent a change of position, size, or light; he left, in fact, the heavens as an inheritance to those who should come after him, and who possessed sufficient genius to turn his labours to good account."

There was an interval of about three centuries between Hipparchus and Ptolemy, to whom I shall presently refer. During this period there was no lack of astronomers who made discoveries of more or less value. It was at this time, indeed, that Poseidonius discovered the causes of the ebb and tide in the sea, and that the calendar underwent "the Julian reform," as it was termed, by Julius Cæsar, who initiated it, entrusting the work to Sosigenes in the year 46 B.C.

Eudoxus fixed the duration of the year at 365¼ days, which was admitted as correct by Sosigenes, and adopted in the Julian calendar. The Julian year lasted 365, and, once in four years, 366 days, which caused a miscalculation of one day every 134 years. This mistake was set right in the Gregorian calendar.*

VII.

History tells us that Julius Cæsar was an ardent lover of the sciences, astronomy in particular. In his interview with the learned Achoræus, he is reported to have said:—"I came to Egypt to encounter Pompey, but your renown was not altogether foreign to my determination. In the midst of war, I have always studied the movements in the heavens,

* See Chapter 16, on the *Division of Time.*

the course of the stars, and the secrets of the gods. My arrangement of time is at least equal to the fasti of Eudoxus, &c." Achoræus, in reply, alluding to the ideas then prevalent as to the solar system, pointed out that "the stars which alone modify the volitation of the heavens, and which extend towards the pole, are supposed to possess varied influences. The sun divides the year into seasons, regulates the interchange of day and night, holds the stars captive by the power of its rays, and limits their wayward course to its centre. The moon, with its varied phases, mingles the land and the sea. Saturn influences the cold regions and the snowy zone; Mars, the winds and the thunder; Jupiter, the air and the unchanging ether; the productive Venus preserves the germ of universal life; Mercury is supreme over the vast expanse so soon as it reaches the region of the sky, where the constellation of Leo is lost in that of Cancer, where Sirius pours forth his darting fires, where the changing cycle of the year is effected in Œgoceros and Cancer, mysterious witness of the sources of the Nile."

We know that Cæsar took a real interest in astronomy, and that he wrote a treatise about it. Pompey, too, was attracted by this science. Leaving Lesbos, bowed down by grief at the defeat of his army, and looking with apprehension at the future, he endeavoured to find distraction from his cares in a conversation with the pilot, and his mind became partially reassured by contemplation of the starry sky:—"He then talked with the pilot about all the stars, inquired how he ascertained the approach to land, and the means of measuring by the heavens the distance which the ship had accomplished; what stars indicated Syria and Libya. The pilot's answer was that he and his fellows never allowed themselves to be guided by a star slowly declining in the firmament, for they would only deceive the sailor, who preferred to trust the never-setting axis which receives light from the twofold Arctos. . . . ."

VIII.

The remainder of astronomy may be divided into five leading systems—those of Ptolemy, Copernicus, Tycho-Brahé, Descartes, and Newton. Ptolemy was a celebrated mathematician. He was born at Pelusium, though Theodorus Meliteniotes states that he was a Thebain, and that he first saw the light at Ptolemais, the capital of that province. At an early age he went to Alexandria, where he founded a school, which enjoyed great celebrity about 175 B.C. Endowed perhaps with more application than genius, he collected and arranged the works of his predecessors, especially those of Hipparchus, and though he did not correct all their mistakes, he was nevertheless the greatest astronomer of his day, and his definite system has continued to be named after him. These his labours have been preserved to us by the Arabs in a well-known work called the *Almagestes.*

His theory was, that the world is composed of two regions: the elementary and the ethereal. The first comprised bodies which the ancients regarded as the four elements: to wit, the earth, motionless, in the centre of the world; water, covering a great part of the earth's surface; air, which is above the earth; and fire, which is above the air.

The ethereal region, surrounding the elementary region, was composed of eleven skies, which revolved around the earth as around a common centre. Beyond the eleven skies was the empyrean, or abode of the blest. All the celestial bodies moved around the earth, which was motionless in the centre of the world.

This system lasted more than fourteen hundred years. He had an ingenious explanation of the positions and retrogradations of the celestial bodies, for an epoch when no conception had been formed as to the immensity of the heavens and the enormous distance of the stars.

IX.

Copernicus was born at Thorn, Poland, in the year 1472, and he died in 1543. It redounds to his fame that he was the son of a Polish baker, and that by the unaided force of his own genius he raised himself to the highest rank as a *savant*. He visited Italy in order to consult with the most famous astronomers, and, after spending some time at Rome as a teacher of mathematics, returned to Frauenburg, in his own country, where his uncle, who was a bishop, provided him with a canonry.

Copernicus submitted all the then known systems of astronomy to the test of a fresh examination. He discovered the germs of the system which bears his name in the researches of several ancient astronomers, Philolaus more especially; but he made it really his own by the application of countless observations and calculations. Apprehensive of contradiction, he did not publish his ideas till towards the close of his life, and did not, in fact, receive a copy of the book in which they were embodied until the day of his death. G. Donner, in a letter to the Duke of Prussia, says that "the honourable and worthy

Dr. Nicholas Copernicus has let his work appear a few days before his departure from earth, like the death-dirge of the swan."

Fontenelle deems Copernicus happy in the period of his death. "Copernicus," he writes, "was himself very apprehensive as to the reception which his ideas would meet with. For a long time he was unwilling to publish them, and only yielded at last to the solicitations of some persons of influence. But what did he do on the very day that he received the first copy of his book in print? Why, he died, and so cleverly avoided the shower of contradictions which he foresaw as certain to be brought forward."*

The lines in which he gives utterance to his doubts will be read with interest:—"I was long in doubt as to whether I should publish my commentaries upon the motions of celestial bodies, or whether it would not be better to imitate the example of certain followers of Pythagoras, who, instead of committing their ideas to writing, imparted them verbally, communicating them to the adept, and to those who felt an interest in the mysteries of philosophy, as may be gathered from the letter of Lysis to Hipparchus. This they did, not as some surmise, through an excessive spirit of jealousy, but in order that the gravest of questions, which had been deeply studied by men of undoubted capacities, should not be made sport of by the idlers, who have no taste for serious works which bring no gain with them; or by men of limited intelligence, who, giving themselves up to the nominal study of science, make their way into the midst of the philosophers like drones amongst bees. The more I hesitated and resisted, the more my friends

* Fontenelle's *Pluralité des Mondes.*

pressed me. Nicholas Schomberg, Cardinal of Capua, a man of deep erudition, and my most intimate friend Tideman Gysius, Bishop of Culm, as well read in the Scriptures as he was learned in the sciences, were specially urgent in their appeals. The latter put so much pressure upon me that at last I agreed to publish the work which for seven-and-twenty years I had kept to myself."

Fig. 6.—Portrait of Copernicus, engraved by J. Falck.*

In Copernicus' system, the sun is motionless in the

* The portraits of Copernicus and the three which follow are from the collection of M. Ambroise Firmin-Didot.

centre of the universe, the earth is classed amongst the planets, the moon is one of the earth's satellites; all the planets revolve around the sun, which is the general centre of the universe; they traverse, at different times, orbits oval or elliptical.

The earth is subject to three motions, which explain the annual and daily motions of the heavens. The first, one of rotation upon its axis, is from west to east, describing the equinoctial circle in the course of the day and night. One effect of this rotation is, that the sun and the stars, though motionless, seem to rise and set each day, and to follow a fixed inclination from east to west.

The second is an annual motion of the earth round the sun, by which, in the space of 365 days 16 hours, it accomplishes its course in the ecliptic circle, but in the inverse direction to the order of the signs; that is to say, that when itself in Capricorn, the sign of the zodiac which answers to winter, it sees the sun in the summer sign, Cancer, and is in the summer season. When it corresponds to Cancer, it sees the sun in the winter sign, Capricorn, and is in the winter season.

The third is a motion of the earth upon itself, by which, while keeping its axis continually turned towards the same point of the sky, it successively exposes each part of its surface to the sun in the course of the year.

These two latter motions, combined, are the cause of the unequal length of the days and nights, and the vicissitude of the seasons.

Copernicus is compelled to place the stars at an incalculable distance, because the earth traverses each year, in its revolution round the sun, an orbit of more than 599,581,708 miles; so that, at the end of six months, it must be nearly 209,853,595 miles distant from the spot where it then was. This is of no consequence, and does not prevent his system, established upon a mathematical basis, from being the simplest, the most natural, and the truest in the world. Copernicus must, therefore, be looked upon as the founder of modern astronomy.

His contradictors said:—" If it were true that the sun was in the centre of the planetary system, and that Mercury and Venus revolved around it, in an orbit nearer to it than that of the earth, these two planets would have phases of their own. When Venus is on this side of the sun, she would have a crescent shape, like the moon going down at night; when she forms a right angle between the sun and us, she would be in shape like the first quarter of the moon. And yet such a thing is never seen." Copernicus' reply was that such undoubtedly was the case, as would be seen some day if instruments could be brought to a sufficient degree of perfection. And so it happened at Florence seventy years later. Galileo, exploring the heavens with a newly-constructed glass, in the end of September, 1610, perceived that Venus had phases like the moon. He could not restrain the ejaculation, " Oh! Nicholas Copernicus, could you but have lived to enjoy this recent discovery, which so fully confirms your ideas!"

X.

Tycho-Brahé was born at Scania, in 1546, and belonged to one of the noblest families in Denmark. From infancy he displayed a strong taste for astronomical observations. He travelled all through Germany and Switzerland to visit the different observatories and learn the methods then in use, and he was entrusted with this mission by the King of

Denmark, who gave him the Island of Huen to take his observations. There he built the celebrated observatory

Fig. 7.—Portrait of Tycho-Brahé, engraved by de Gheyn.

which he called Uranienburg, residing there for seventeen years. At the death of the king, his successor, Frederick, showed him less favour; so he left Denmark, and proceeded to Bohemia, where the Emperor Joseph II. afforded him a permanent hospitality. He died at Prague in 1601. To him we owe numerous observations, the fruit of his twenty years' residence in the Island of Huen, and many of them, marvellously exact, have assisted Kepler to his discoveries. When a new star appeared in Cassiopea, in 1572, Tycho-Brahé compiled a catalogue, in which the position of more than a thousand stars was fixed with a precision most remarkable at a period antecedent to telescopic observation.

Tycho-Brahé attempted to upset the system of Copernicus, then in great repute, and to connect it with that of Ptolemy; wherein, of course, he failed. He maintained that the distance from the fixed stars to the sun, as laid down by Copernicus, was very improbable; and, desirous of upholding certain Scriptural passages which were incorrectly said to contradict this system, he re-established the earth in its old position, placing it motionless in the centre of the world, and making the moon, the planets, and fixed stars revolve round the sun, while the latter in turn moved round the earth with all its planetary *cortége*. Thus he was one with Copernicus in looking upon the sun as the centre of the constellations we have named, and with Ptolemy in holding that the earth is motionless, the sun and the stars revolving around it.

In this hypothesis Venus and Mercury pass, during part of their revolution, between the sun and the earth, which explains pretty correctly their phases, as seen through a glass, which are very like those of the moon. This system, though it did credit to Tycho-Brahé's ingenuity, was universally rejected.

XI.

Descartes, the great French philosopher, was born at Lahaye (Touraine) in the year 1596. In early life he followed the profession of arms, serving as a volunteer under Maurice of Nassau and the Duke of Bavaria; but he soon left the service. He then travelled through Germany, Holland, and Italy, and paid several visits to Paris, where he formed the acquaintance of several scientific men. After remaining for several years undecided as to the choice of a career, he resolved to give himself up to solitary study, and for this end left France for Holland, where he lived for some time in the strictest seclusion.

Descartes' works earned him great renown, but they also drew down upon him many contradictions, and even persecution.

The Princess Elizabeth, daughter of the Palatine Elector Frederick V., delighted in his society. Mazarin gave him a pension of a thousand crowns, and Queen Christina invited him to reside at her Court. Flattered by this request, Descartes went to Stockholm, in the winter of 1649, but he died there a few months later from the severity of the climate, at the age of fifty-four. His remains were brought back to France in 1667, and entombed with great ceremony in St. Geneviève.

He is looked upon as the father of modern philosophy. To him we owe the application of algebra to geometry; he first discovered and proved the existence of the centrifugal forces, which maintain the universal equilibrium by balancing in all directions the action of gravity. His system, generally known as the vortices of Descartes (*tourbillons de Descartes*), is very similar to that of Copernicus.

The word *vortex*, thus used, is intended to signify a certain quantity of matter divided into an infinity of very small particles, which revolve all together around one common centre, while each one of them revolves round a centre of its own. For instance, applying this kind of motion to the stars, the *vortex* (*tourbillon*) in which we are placed is composed of the sun and the planets which revolve around it, as they do also upon themselves. Descartes

Fig. 8.—Portrait of Descartes, engraved by Jonas Suyderhoeff.

admits three kinds of celestial bodies—1st, the fixed stars, all of which are suns; 2nd, the planets, which revolve round the suns; 3rd, the moons, which revolve round the planets.

This system did not come scathless out of the analytic examination to which he himself subjected it, but this great thinker, by his creative researches and fruitful discoveries, gave a great impulse to human thought, and a spur as deep as it was durable to science and philosophy.

XII.

Newton, the most illustrious of English *savants*, was born in the year 1642, at Woolstrop, Lincolnshire. He is placed in the first rank of mathematicians, natural philosophers, and astronomers, yet it may be said that his discoveries were, to a certain point, led up to by Descartes. His mother had intended to make a farmer of him, but as he showed no aptitude for this calling, she allowed him to follow his own inclination. He was sent, at the age of thirteen, to Cambridge, where Dr. Barrow was his mathematical tutor. He soon learnt more than his tutor knew, and made his greatest discoveries in mathematics before he was three-and-twenty; in particular that of the binomial named after him, and of the infinitesimal calculation which he called the calculus of fluxions (differential calculus).

In 1665 he left Cambridge, in consequence of the plague, and returned to Woolstrop, where, it is said, he saw the apple fall, which led to his first ideas as to universal gravity and the system of the universe.

It seems that in 1692 his reason momentarily gave way, either as the result of a fire which destroyed several of his papers, or because he had laboured too hard, and after that time he did not publish any original work of importance, contenting himself with a revision of previous publications. In 1699 the French Academy of Sciences elected him a foreign associate, and in 1703 the Royal Society chose him as President—which title he retained until his death. His

Fig. 9.—Portrait of Newton, engraved by J. Smith.

latter years were embittered by a dispute in which he was engaged with Leibnitz, whom he accused of plagiarism, the result of which was that, while Newton was admitted to have the priority, Leibnitz, on the other hand, proved that he had also made the self-same discovery.

An English poet has termed him a man of pure intelligence, sent to man by the Creator to explain the works which He had created.

His profound knowledge of mathematics led him to the discovery of the curve described by a body in its revolution round a centre, to which it is attracted by a force *proportional* to the mass of the central body, and *decreasing* according to the laws of gravity. He thus ascertained that all the celestial bodies revolve in the four principal curves of the *conic sections*, viz., the planets in ellipses, the satellites in circles, the comets parabolically or hyperbolically.

The summary of his system is this: Just as all weighty bodies gravitate to the earth's centre, so do the bodies which compose the universe gravitate, by the force of attraction, towards the sun, which is their common centre. But as the planets, if they were only governed by the force of attraction, that is to say, by the force which the sun exercised in attracting them towards itself, they would gradually be drawn into that celestial body. Newton adduced two moving powers given them by the Creator at the beginning of the world, the first of which was a centripetal force impelling the planets towards the sun; the second a centrifugal force, which hurried them away from it, the one counterbalancing the other.

Thus the earth, instead of being carried far away from the sun by the centrifugal force, is maintained, by the action of the two combined, in its orbit, and compelled to describe around it an ellipsis of which it occupies one of the foci.

Newton also calculated the motions of the satellites and the routes followed by the planets with an accuracy confirmed by subsequent observations.

The flood and ebb of the sea, the precession of the equinoxes, the nutation of the earth's axis, the difference between the *true* and the *mean* time, are but effects evolved from the law of universal gravitation.

In the course of this work I shall have an opportunity of developing ideas which can only be glanced at in a rapid review of the history of astronomy.

CHAPTER II.

THE SOLAR SYSTEM.

The Sun—The eight principal planets—The smaller planets—The satellites—Formation of the solar system.

I.

The Sun, and its *cortége* of orbs, which do not emit any light of themselves, constitute what we call the solar system. It is composed, firstly, of the Sun, which, for astronomical purposes, is generally designated by the sign ☉, the diameter of which is 108 times that of the Earth, and which revolves upon its own axis once in about 25 days, 10 hours; secondly, of eight principal planets, and 128 smaller or *telescopic* planets, the orbits of which are embraced between those of Mars and Jupiter, at about co-equal distances from the Sun.

The principal planets, enumerating them according to their increasing distance from the Sun, have been called:—

1st, *Mercury*, represented by ☿, whose mean distance from the sun is 35,393,000 miles, with a revolution round that luminary of 87 days, 23 hours, 15 minutes, and a diameter two-thirds that of the Earth.

2nd, *Venus*, ♀, with a mean distance from the Sun of 66,130,000 miles, a revolution of 224 days, 16 hours, 48 minutes, and a diameter nearly equal to that of the Earth.

3rd, the *Earth*, ⊕, with a mean distance from the Sun of 91,430,000 miles, a revolution of 365 days, 6 hours, 9 minutes, and a diameter of 7,901 miles.

4th, *Mars*, ♂, with a mean distance from the Sun of 139,312,000 miles, a revolution of 686 days, 23 hours, 31 minutes, and a diameter half that of the Earth.

5th, *Jupiter*, ♃, with a mean distance from the Sun of 475,693,000 miles, a revolution of 4,332 days, 14 hours, 2 minutes, and a diameter eleven times that of the Earth.

6th, *Saturn*, ♄, with a mean distance from the Sun of 872,135,000 leagues, a revolution of 10,759 days, 5 hours, 16 minutes, and a diameter nearly ten times that of the Earth.

7th, *Uranus*, ♅, with a mean distance from the sun of 1,752,851,000 miles, a revolution of 30,686 days, 17 hours, 21 minutes, and a diameter four times that of the Earth.

8th, *Neptune*, ♆, with a mean distance from the Sun of 2,746,271,000 miles, a revolution of 60,118 days, and a diameter nearly five times that of the Earth.

The solar system is further composed of 21 planetary satellites: 1 for the Earth (the *Moon*, represented by the figure ☽); 4 for Jupiter, 8 for Saturn, 6 for Uranus, 2 for Neptune, and comets the number of which increase every day.

Kepler suspected the existence of a planet between Mars and Jupiter, and Father Secchi says that he was the first to discover a certain regularity in the distribution of the planets. There seemed, however, to be some anomaly in the distance which separated Mars from Jupiter, and, upon this ground, he predicted that some hitherto unknown star would eventually be discovered in the space between them: a prediction which was more than verified two centuries afterwards,* for no less than 128 have already come under observation, as will be seen by the appended table, and fresh ones are being discovered every day. M. Le Verrier has calculated that they are not, put together, equivalent to a body one-third the size of the Earth, for he argues that if they were larger than that their attraction would have led to greater variations in the motions of the perihelion of Mars than have hitherto been noticed.†

II.

MINOR OR TELESCOPIC PLANETS BETWEEN MARS AND JUPITER.

(1) Ceres.
(2) Pallas.
(3) Juno.
(4) Vesta.
(5) Astræa.
(6) Hebe.
(7) Iris.
(8) Flora.
(9) Metis.
(10) Hygeia.
(11) Parthenope.
(12) Victoria.
(13) Egeria.
(14) Irene.
(15) Eunomia.
(16) Psyche.
(17) Thetis.
(18) Melpomene.
(19) Fortuna.
(20) Massilia.
(21) Lutetia.
(22) Calliope.
(23) Thalia.
(24) Themis.
(25) Phocea.
(26) Proserpine.
(27) Euterpe.
(28) Bellona.
(29) Amphitrite.
(30) Urania.
(31) Euphrosyne.
(32) Pomona.
(33) Polyhymnia.
(34) Circe.
(35) Leucothæa.
(36) Atalanta.
(37) Fides.
(38) Leda.
(39) Lætitia.
(40) Harmonia.
(41) Daphne.
(42) Isis.
(43) Ariadne.
(44) Nysa.
(45) Eugenia.
(46) Hestia.
(47) Aglaïa.
(48) Doris.
(49) Pales.
(50) Virginia.
(51) Némausa.
(52) Europa.
(53) Calypso.
(54) Alexandra.
(55) Pandora.
(56) Melete.
(57) Mnemosyne.
(58) Concordia.
(59) Olympia.
(60) Danae.
(61) Echo.
(62) Erato.
(63) Ausonia.
(64) Angelina.
(65) Maximiliana.
(66) Maia.
(67) Asia.
(68) Leto.
(69) Hesperia.
(70) Panopea.
(71) Niobe.
(72) Feronia.
(73) Clytie.
(74) Galatea.
(75) Eurydice.

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* Father Secchi on *The Sun.*

† Volume xxxvii. p. 793, of the Journal of the *Académie des Sciences*, p. 334.

(76) Freia.
(77) Friga.
(78) Diana.
(79) Eurymone.
(80) Sappho.
(81) Terpsichore.
(82) Alcmene.
(83) Beatrix.
(84) Clio.
(85) Io.
(86) Semele.
(87) Sylvia.
(88) Thisbe.
(89) Julia.
(90) Antiope.
(91) Egina.
○ Undina.
(93) Minerva.
(94) Aurora.
(95) Arethusa.
(96) Ægle.
(87) Clotho.
(98) Ianthe.
(99) Dike.
(100) Hecate.
(101) Helena.
(102) Miriam.
(103) Hera.
(104) Clymene.
(105) Artemis.
(106) Sylvia.
(107) Camilla.
(108) Hecuba.
(109) Felicitas.
(110) Lydia.
(111) Ate.
(112) Iphigenia.
(113) Amalthea.
(114) Cassandra.
(115)
(116) Sirona.
(117) Lomia.
(118)
(119)
(120)
(121)
(122)
(123)
(124)
(125)
(126)
(127)
(128)

Planets 115, 118, and the remainder have not yet been named.

III.

The revolution of the Earth round the Sun, &c., &c., is now well known; but what is not so generally known, and what creates some surprise amongst novices, is that the solar system, that is to say, the Sun and the Earth, the planets and the moons, have an incessant tendency to shift towards the constellation of Hercules.

Herschel proved that the apparently inextricable irregularities of so many special stellar motions are mainly due to the displacement of the solar system; and that the point in space, towards which we are advancing each year, is situated in the constellation of Hercules. These results are magnificent. The discovery of the specific movement of our system will always count as one of Herschel's greatest achievements, notwithstanding the previous conjectures of Fontenelle, Bradley, Mayer, and others. In juxtaposition to this great discovery must be placed another which seems destined to yield still more magnificent results, and which was given to the world in 1803. I refer to the discovery that certain stars are reciprocally dependent, connected with each other as the planets of our system and their satellites are to the Sun.*

Father Secchi has set forth in such simple yet clear terms, the ideas generally accepted as correct by modern science concerning the formation of the solar system, that we cannot do better than quote him :—

"Astronomers of the present day are agreed that our solar system is due to the condensation of a nebula, which formerly extended beyond the limits now occupied by the most distant planets. This nebula was originally endowed with a slow rotatory motion, which must have gradually become accelerated. According to a law of mechanics, known as *the law of superficies*, every disengaged particle must move in such a way that its radius-vector will describe equal superficies at equal intervals; whence it follows that, the radius being gradually lessened by progressive contraction, the arc described during the unity of time must have increased, so as to keep the superficies from undergoing variation. An augmentation of centrifugal force results from this increase of speed, and when this force comes to equal the force of gravitation, rings are formed which remain suspended around the central mass. As the speed goes on increasing, these rings are broken, and the different fragments, each one in obedience to the laws of attraction,

* *Astronomie Populaire.*

in their turn form new masses which are isolated from each other, and which become centres of action similar to the principal centre. These masses have in turn been surrounded by rings of a secondary order, some of which are still in existence, while others, getting dispersed, have gone to form satellites.

"This theory, expounded by Kant, Herschel, and Laplace, has been confirmed by the ingenious experiments of M. Plateau. A mass of oil poured into a mixture of water and alcohol of the same density as itself, will be seen to assume the spherical shape which molecular attraction would tend to give it. If it is made to turn around its vertical diameter at an increased rate of speed, the sphere will be found first to flatten, and after a certain time to detach a ring similar to that of Saturn. As the speed is still further increased, the ring will be broken up, and form into small spheres revolving upon their own axis and around the main mass.

"The matter which composed the primitive nebula must have been far more rarefied than that which we are able to obtain with the best of pneumatic machines, and has since become enormously contracted and condensed, leaving the planets and the satellites at various distances. The Sun is the still incandescent and gaseous residue of the primitive mass. We find in the sidereal world traces of this formation, in our planetary world, the rings around Saturn, in the stellar world, the annular nebulæ. These masses are composed of a matter which is still gaseous, and they seem to constitute worlds in course of formation." *

M. Inrichs arrives at the important conolusion that the

* Father Secchi on *The Sun*, p. 332. Also *Vestiges of Creation*.

law of progressive condensation is bound up with the third law of Kepler, and that the latter is itself the outcome of universal gravity acting in direct ratio with the masses and in inverse ratio with the square of the distances. Thus the law as to the formation of the planetary system would be but a consequence of universal gravity.

M. Delaunay, of the French Institute, also remarks: "The great law of universal gravity, which we owe to the genius of Newton, has introduced unity into the science of astronomy, and enabled us to attach to one particular cause all the peculiarities presented by the motions of the celestial bodies."*

* *Rapport sur le progrès de l'Astronomie*, p. 1.

Fig. 10.—Urania, antique statue, now in Sweden.

CHAPTER III.

LIGHT AND THE DETAILS OF SPECTRUM ANALYSIS.

Light enables us to recognise the stars—Revelations by spectrum analysis—Hypothesis of the emission, and that of undulations—Laws of light—Various measurements of its speed—The solar spectrum—Chemical action of light—Length of luminous waves—Analogy between sound and light—Molecular vibrations and atomic vibrations—Mode of propagating light—Refraction and reflection—Luminous interferences—How light added to light produces darkness—Triumphal entry of the spectrum analysis into science—Its history—Metals revealed by analysis of the spectrum which they elicit during combustion—Important chemical and spectral laws—Curious experiments in physiology — Undreamed of horizons in astronomy—Ignition in the celestial domain — Spectra of planets, moons, and stars—Substances discovered in the stars — Nature of nebulæ—Movements of the stars revealed by their spectra — Discovery of the nature of comets—Matter following in the track of the aerolites—Unity of composition extending to all the luminaries in the universe — The inhabited celestial spaces.

I.

It is light which reveals to us the stars, and therefore it is by its aid that we must commence our study of them.

Spectrum analysis has opened up a new field to astronomy, and laid bare horizons of which no one had ever dreamed. It is wonderful to reflect that a mere ray of light, that is to say, an imperceptible movement communicated to ether in boundless space, is transformed, by the aid of modern science, into a telegram sent from the worlds of the infinite to instruct us, not only as to the nature of the elements which compose them, but as to the motions which hurry them through space, and which we should be unable to ascertain with the most perfect of telescopic instruments.

These revelations, exceeding all that the wildest imagination could have conceived, are absolutely stupefying; and, as an elementary knowledge of the subject is almost a necessity even for those who do not dabble in science, I may, after giving a few notions about light in general, expose very succinctly the most important points of this procedure, which is enriching astronomy each day with new and brilliant conquests.

Few sciences give rise to so many surprises as that of light, in regard to which two very different hypotheses have been formed—that of *emission*, to which the name of Newton long lent great authority, and that of *undulations*, started by Descartes, and now very generally adopted.

The *hypothesis of emission* supposes a luminous body to propel in different directions a material substance of extreme tenuity, so subtle as to render it impossible to ascertain its weight and solidity; a substance which, passing through certain bodies without any loss of velocity, may yet be brought to a stop by others. When this substance comes in contact with an organ of the vision, part of it makes its way into the interior of the eye, and produces the sensation of sight.

In the *hypothesis of undulations*, instead of supposing the transport of a material agent to great distances, it is held that the vibrations of luminous bodies are communicated to the atoms of an all-pervading *ethereal fluid*. These vibrations, propagated through this fluid, reach the organ of vision, which in turn transmits them to the optic nerve. In this hypothesis, the nature and the transmission of light would be analogous to the nature and transmission of sound, light being produced by atomic, and sound by molecular vibrations.

The most recent experiments of the savants—the researches upon *interferences,* amongst others—have led to a general acceptance of this latter hypothesis.

II.

It is known that light declines or diminishes in force or intensity in proportion as it recedes from the point whence it emanated. This diminution is in *direct ratio to the square of the distance;* for instance, if the distances are 1, 2, 3, 4, &c., the quantities of light received at distances 2, 3, 4, &c., will be 4, 9, 16 times, &c., less than at distance 1.

Rœmer, the Danish astronomer, by an observation of the eclipses of Jupiter, succeeded in ascertaining the speed of light. He noticed that it always took 16 minutes and 36 seconds longer to reach the Earth when Jupiter was in conjunction with the Sun, upon the other side of the ecliptic, than when that planet was upon our side in opposition to the Sun. Hence he concluded that light must take that time to traverse the whole diameter of the terrestrial orbit, that is to say, about 182,000,000 miles, and that consequently it must be 8 minutes 13 seconds in coming from the Sun.

Until the experiments of M. Fizeau it was never supposed that the speed of light could be arrived at by terrestrial observations; but by an extremely simple procedure he proved that the luminous movement travelled $11\frac{1}{4}$ miles in the $\frac{1}{1800}$ of a second. This figure is almost the same as that arrived at in antecedent observations, but a slight want of clearness in the impressions obtained prevents this measurement from being so precise as those taken in the heavens.

M. Foucault tried a new mode of measurement, in 1862, by means of a revolving mirror, and ascertained that light had a velocity of 186,250 miles a second. The procedure alluded to above gives 192,500 miles, so that there is a marked difference in the results.

Many objections have been taken to this latter method. The light had only traversed a space of 37 feet, and in this short distance it had undergone five reflections and pierced an object-glass, which, it was suggested, might have occasioned a diminution of velocity. It was urged also that no one can tell what is the totality of phenomena which take place in a reflection, and that in fact the result of the experiment did not or might not apply to light in an open space. Nor can one place unlimited reliance upon the extreme micrometrical divisions which it was necessary to make use of.

M. Cornu made some further experiments for the purpose of ascertaining the exact rate at which light travels, the results of which he has recently laid before the French Academy of Sciences.

His mode of observation is in the main similar to that adopted by M. Fizeau, except that he has perfected certain details, and amongst them may be pointed out a means of registering by electricity the speed of the notched wheel, which it is all the more necessary to ascertain, for this wheel is used for making a direct comparison as to the velocity of light. His own point of observation was an attic in the Polytechnic School, and the other point a room in the barracks on Mont Valérien. In this way M. Cornu has obtained sufficient data concerning the velocity of light to enable him to decide between the rate of 192,500 or 193,750 miles, as given in former calculations, and that of

186,250 miles, as established by M. Foucault in his experiments with the revolving mirror.

To quote his own words:—"My observations concord with those of M. Foucault, though it is necessary to point out that his experiments required verification, both because their details and the mode of procedure, not having been made public, had not been subjected to discussion, and because the method of the revolving mirror is open to grave objections, into the nature of which I cannot enter at present. M. Fizeau's method is, on the other hand, free from these objections. Astronomers, again, will find in this new valuation of the velocity of light a strong confirmation as to the parallax of the Sun 8″.86, which is obtained by combining this number with the constant of aberration. This was ascertained by M. le Verrier, after three series of observations relative to the movement of the planets, especially of Mars and Venus. So we see that in astronomy it is impossible to overestimate the importance of determining precisely the velocity of light." *

III.

When objects are looked at through a glass prism, not only do they appear to have been considerably displaced by the deviation of the luminous streaks which pierce the prism, but also to be covered with bands of the brightest colours.

If a prism be so arranged that a luminous streak shall fall obliquely upon one of its facets, and, as it emerges, be caught upon a screen or a picture, the result will be an

* Paper read at the *Académie des Sciences*, Feb. 10, 1873.

oblong figure of a thousand variegated colours, which has received the name of *solar spectrum.**

The law of reflection and refraction, and the various ways of magnifying objects by means of the lens, were known before Newton's time, but the nature of light and the origin of colours were still a mystery. Without questioning the fact of their being produced in this way, no one had suspected that a ray of white light was composed of a large number of single rays, each of itself capable of imparting a colour of its own. Delille expresses this idea in the lines:

> "Dans les mains d'un enfant, un globe de savon
> Dès longtemps précéda le prisme de Newton,
> Et longtemps, sans monter à sa source première,
> Un enfant dans ses jeux disséqua la lumière.
> Newton seul l'aperçut, tant le progrès de l'art
> Est le fruit de l'étude et souvent du hasard."

There are seven shades especially noticeable in solar light as decomposed by the prism, which have on this account been termed the principal orders. Taking them in their natural order, they are: *red, orange, yellow, green, blue, indigo,* and *violet.*

In explanation of these phenomena, white light is looked upon as composed of an infinity of rays, differing in colour, and more or less susceptible of refraction, which separate from each other as they pass through the prism.

The first point noticed in solar radiation is the light which we receive, and the heat which accompanies it; but there is also a third and very important order of phenomena, viz., chemical action. Its influences are not a thing apart, but the varying effects of one single cause, consisting simply

* See same author's *Histoire des Météores*, fig. 4, p. 76.

of a series of undulations which only differ from each other in regard to their length and the rapidity with which they are produced.

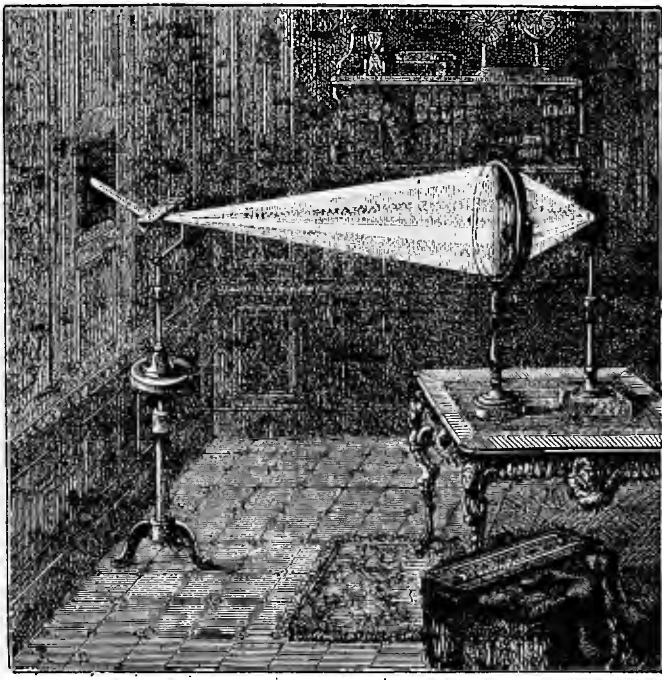


Fig. 11.—Recomposition of light.

The waves, whose length is comprised between 768 and 369 million fractions of a millimètre (·03987 of an inch), have the power of making our optic nerve vibrate, and thus produce the sensation of light. The diversity of colours depends only upon the length of the waves, the longest being red, and gradually toning off to violet. With the colours extending from the green to the violet, the luminous waves also have the power of separating the molecular groups, and producing chemical effects. These luminous waves extend far beyond the visible spectrum into a region whither the eye cannot penetrate, but they can be recognised by the agency of photogenical preparations. From the green to the red the waves become longer, and possess the property of agitating the molecular groups by a purely physical action, but, in most cases, without decomposing them. These waves also extend beyond the red, and thus form a second part of the spectrum, which is invisible.*

We know that sound is produced by molecular, and light by atomic vibrations, and that the general laws relating to these different kinds of vibrations are the same; but it is worthy of remark that the sound vibrations extend much further than those of light, since the latter, sensible to the eye, do not embrace more than what is known in acoustics as *an octave.*

IV.

Light always travels in a straight line, through a region which is perfectly and uniformly diaphanous. But a mere difference of density is sufficient to bring about its deviation from the straight line, and to break it up into heterogeneous quantities.

As the various strata of the air all vary in density, it follows that the light of the stars does not come to us in a straight line, and that we do not see them in the position which they actually occupy. At the horizon there are at least 33′ of refraction, or, in other words, rather more than the largest diameter of the Sun or the Moon. Thus, when the lower margins of the latter luminaries seem to

* Father Secchi on *The Sun*, Part II.

be just upon the horizon, in reality the whole of their disc is submerged beneath it (see fig. 12). The same illusions take place in our observations of the stars and of far distant

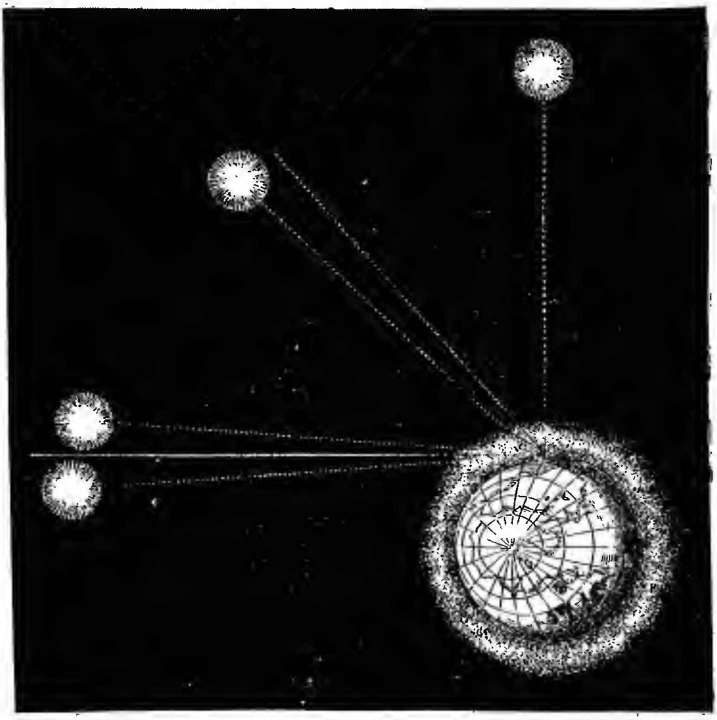


Fig. 12.—Phenomena of refraction.

bodies. But as light, in its passage through the various strata of the atmosphere, does not encounter any sudden change of density, so it does not break suddenly off, as, for instance, in its passage from the air into water or a tumbler. It follows a curved line, and not a broken one. The refraction of the light from the Sun and Moon gives us the benefit of their presence for a longer period, as it anticipates the

Fig. 13.—The Moon, as seen upon the horizon, appearing flattened by the refraction of its light.

hour of their rising, and delays that of their setting. It is to refraction that we owe the dawn which heralds the brightness of day, and the twilight which precedes the darkness of night. The refraction of light also flattens these luminaries, and makes their disc look oval. This is all the more pronounced the nearer they are to the horizon, and, as Biot has remarked, "when seen from eminences near the sea-shore it sometimes equals a fifth of the apparent diameter of the Sun. The Moon's disc presents the same phenomenon."

Light which, having passed through a very refracting region, reaches a space where the refraction is not so great, will sometimes stop at the point which separates the two spaces, undergo a total reflexion, and travel back through the space which it had already traversed. This peculiar phenomenon takes place whenever the rays reach the surface of emersion at too great an angle of obliquity. The fact of this total reflexion explains all the varieties of magical phenomena known as mirages.

In my work on the "History of Meteors," a chapter is specially devoted to this subject, and contains many facts connected therewith which I ascertained during my travels in the New World.

V.

The phenomena of luminous interferences will appear to people who are not well acquainted with optic discoveries, perhaps even more marvellous and incredible than those of the mirage.

Supposing a bright ray of solar light to come in direct encounter with a sheet of white paper, for instance, it follows that the portion of the paper on which the ray strikes will be made to shimmer. But what seems incredible is, that this portion may be made quite dark without touching the paper, without arresting or diminishing the luminous ray, but, on the contrary, by increasing it.

The magic mode of changing light into shade, day into night, is even more remarkable for its simplicity than for its prodigious effects, consisting, as it does, in conducting on to the paper, by a slightly different trajectory, a second luminous ray, which of itself would have made the paper still more brilliant. One might imagine that the two rays, when they met, would have this effect; but, on the contrary, light added to light produces darkness! The movements of these rays neutralise each other, and the light ceases to cast any lustre. It will happen, however, that these luminous rays, by reason of their direction, only partially neutralise each other, in which case there is merely a diminution of the lustre.

These are the curious phenomena, which, obliterating or diminishing light by the adjunction of a luminous ray, have received the name of *interferences*.

Of the thousand rays of variegated shade and refrangibility which compose colourless (or white) light, those only are capable of neutralising each other which possess co-ordinate colours and refrangibility. Thus, a red ray cannot be made to obliterate a green ray.

If, again, two white rays cross each other at a given point, it may happen that, in the infinite series of various coloured lights of which they are composed, the red ray, for instance, will alone disappear, and that the point of their intersection will become green—green being white minus the red.

Two rays which have been changed from the state of natural light into polarised rays following the same direction, will still possess the property of *interference*, combining or neutralising each other like, and under the same conditions as, ordinary rays.

Two rays which pass, without any intermediate stage, from their natural state into that of rays polarised at right angles, are definitely deprived of the property of *interference*. Though their course, the character, and the thickness of the spaces they traverse be modified in a thousand ways; though they be brought back to the state of reflections combined of the requisite properties, or to parallel polarisations, it will be impossible to make them obliterate each other.

But if two rays which were polarised in two rectangular directions, and which could not, therefore, have any influence upon each other, had in the first place undergone parallel polarisations when transformed from their natural condition, they could be made to obliterate each other merely by restoring them to the state of polarisation with which they were originally endowed.

It is impossible to avoid a feeling of surprise when one learns, for the first time, that two luminous rays are capable of destroying each other, and that darkness may result from the conjunction of two lights; but it is still more extraordinary that this property can be given and then taken away from them, in some cases momentarily, in others altogether. The theory of *interferences*, looked at from this point of view, might seem rather the product of a diseased brain, to use Arago's expression, than the strict and inevitable outcome of numerous experiments which cannot be controverted.

It was in this theory that Fresnel found the key to all the beautiful phenomena of colouration engendered by the crystallised plates, or films, which are endowed with double refraction, proving that they were special instances of *interference.* Dr. S. Young has achieved his greatest renown by his experimental and complete demonstrations concerning *interferences*, and the principles which he laid down were set forth and still further applied by Fresnel.

The *theory of undulation* suggested by Descartes in explanation of the phenomena of light, had been already accepted by the *savants*, and the most recent experiments in regard to *interference* confirm its perfect accuracy.

Those who would reconcile the Bible with modern science will gather, from what I have stated as to the nature of light, that Moses may have said with truth that light was created before the celestial luminaries, inasmuch as it is but a manifestation of undulations.

VI.

We now come to the question of the spectrum analysis. It is not only the sunlight which can be decomposed and made to produce a spectrum, but any other kind of light as well. It is, however, very remarkable that these lights, when decomposed, give different spectra, and by examining their character that of the bodies which produce them can also be ascertained.

The study of a body by the analysis of its spectrum is termed the *spectrum analysis.*

M. Delaunay, of the Institute, gives the following *résumé* of this discovery, so fruitful in its consequences. In order to separate, if possible, the partial images produced by the various unmixed lights, of which uncoloured (or white) light is composed, one naturally endeavours to make each of these images as narrow as possible, to prevent them from encroaching upon each other. This may be done by admitting the light from without through an opening in the shape of a narrow chink, standing some distance back to examine it, and placing the prism in such a way that its square edges will be parallel to the length of the chink. Wollaston tried this plan in 1802, a century after Newton had discovered the solar spectrum; and the result partially answered his expectations. Submitting certain artificial lights, such as the flame of a candle and an electric spark, he obtained results analogous to, but not identical with, that yielded by the sunlight. Yet Wollaston, in thus looking with the naked eye through the prism, obtained but a vague glimpse of the phenomenon which he was in research of, and which Fraunhofer was destined to discover in all its splendour.

In 1815 that noted Munich optician, without being aware of the essay made by Wollaston thirteen years previously, endeavoured to scan through a prism the spectral outline of a ray of light admitted through a narrow chink; and to observe it more closely he made use of a glass. The spectrum then appeared to him traversed, not by four or five dark rays, as it did to Wollaston, but by a far greater number. He saw, in fact, as many as five or six hundred. He then proceeded to measure accurately the relative positions of a large number of these rays, and made a drawing of the spectrum, with 354 of them in their respective places. He also ascertained, like Wollaston, that the spectra given by artificial lights are distinguished by a special disposition of these rays, and, in some cases, even by a complete absence of them.

Fraunhofer's discovery drew the attention of scientific men to the subject, and numerous experiments were undertaken for the purpose of studying the curious phenomena which he had revealed to the world.

It must be added, that a very remarkable relation has been established between the brilliant rays produced by gas in a state of combustion, and the obscure rays which this same gas creates in the spectrum of a light passing through it. These rays, brilliant in the one case, obscure in the other, occupy absolutely identical places in the spectrum. Where hydrogen gas, for instance, produces a brilliant ray when on fire, the same gas produces an obscure ray by the absorption which it exercises upon an extraneous light passing through it. This remarkable circumstance, known as the *inversion of the spectrum*, was first pointed out by Foucault, in 1849, and definitely established by Kirchhoff * ten years later.

Such are the various phases which the question of spectrum analysis has passed through.

VII.

Thus we find that every substance in a state of ignition yields its special spectrum, and without seeing the body which is burning, we can, by a mere examination of its spectrum, tell to a certainty how it is composed.

Gold, when incandescent, emits a spectrum different from that of silver, and that of silver differs again from other metals, &c.

The main properties of some metals are so alike that it is almost impossible not to confound one with the other in the ordinary mode of investigation, and metallurgists have

* Delaunay's *Notice sur l'Analyse Spectrale.*

consequently resorted to an examination of their spectra when incandescent. By means of spectral comparison and analysis they have discovered differences not to be traced in the substances themselves, and by this procedure have already discovered three new metals: *rubidium*, *cæsium*, and *thallium*.

Spectrum analysis also leads us to an important chemical discovery, which M. Dumas laid before the French Academy of Sciences in 1871. M. Lecoq de Boisbaudran had, some years ago, demonstrated the affinity between spectra of alkaline metals and those of metals coming out of an alkaline soil. He had shown that the displacement of characteristic rays was effected in accordance with the same law as the modifications in the weight of the elementary substances. Messrs. Toost and Hautefeuille, on the one hand, and M. Ditte on the other, having followed up these researches, ascertained that the course of the rays towards the ultra-violet hue manifests itself exactly in the same way as the increase of the atomic weights does for carbon, silica, titanium, tin, and zirconium upon the one hand, and for sulphur, selenium, and tellurium on the other. M. Dumas pointed out that this is but another proof, amongst the many which science already possessed, as to the truth of the principle upon which, in 1827, he established his classification of simple bodies into natural categories.

Spectrum analysis may also be very useful in physiology and medicine. In some cases of poisoning, the toxical element can be ascertained by burning a part of the flesh or excrement, and by decomposing through the prism the light produced by the combustion. It was in this way that M. Lany discovered thallium in the organs of animals to which that substance had been administered.

But it is in astronomy that its results have been most remarkable. This science has made use of the spectrum analysis to extend its researches over milliards of millions of leagues, and by its means has ascertained the character and elements of the countless luminaries which pervade space.

Here is an instance: a brilliant star having suddenly made its appearance (May, 1866) in the constellation of the Corona Borealis, and almost as suddenly vanished, its light was at once submitted to spectrum analysis, and it was proved that this star was one already known as emitting a very dim light, which had momentarily brightened. Its spectrum had great analogy with that of our sun, and we are told by Messrs. Huggins and Miller that "the spectrum of this star, coupled with the sudden outburst of its light, and its almost equally rapid diminution in intensity, make it probable that owing to some vast internal convulsion, enormous quantities of gas were emitted from it, the hydrogen in which must have taken fire by its mixture with some other element, and caused the light represented by the brilliant rays, the flames raising the solid matter in the photosphere of the star to a white heat. The hydrogen burnt out, the light would then have gradually diminished in brilliancy, and the star would resume its normal appearance." It must be borne in mind that, owing to the immense distance of the star in which this *fire* (to use a word which designates the phenomenon with great accuracy) took place, the light must have taken a considerable period to reach us, and that it had been at an end ten, twenty, a hundred years or more, before we were made acquainted with it.*

* Delaunay's *Notice sur l'Analyse Spectrale.*

VIII.

Spectrum analysis, by enabling us to read in a ray of light the nature of the body which produces it, the elements constituting that body, and the changes that take place in it, becomes as it were a messenger from the stars, the confidant of infinite space, the telegraph from incalculable distances, the revealer of the closest secrets, and even a relentless denunciator.

Mr. Huggins has published a work upon the spectrum analysis which contains many new and important facts, and to it we shall often have occasion to refer.

The various spectra differ from each other in many important respects, but they may all be divided into three categories.

1st. The distinctive character of spectra of the *first order* consists in the continuity of those coloured bands broken by no ray, brilliant or obscure. Whence we learn that the light in which this spectrum has its origin is emitted by an *opaque* body, which probably exists in a solid or liquid state. A spectrum of this order does not disclose to us the chemical nature of the incandescent body whence the light proceeds.

2nd. The spectra of the *second order* are formed from coloured rays of light isolated from each other. They indicate to us that the brilliant matter emitted by the light is in a *gaseous state;* and as each element and each component body, which has become luminous without being decomposed, is distinguishable when in a gaseous state by certain rays peculiar to it, it follows that these rays are capable of revealing to us the nature of the bodies from which they are emitted.

3rd. The *third order* comprises the spectra of incandescent bodies, solid or liquid, in which the continuity of the coloured bands is broken by sombre rays. These latter are not produced by the source of light, but by vapours through which the light has passed on its way. Spectra of this kind are yielded by the light of the *Sun* and of the stars. The *group of sombre rays* produced by each vapour is identical, as regards their number and their place in the spectrum, with the group of brilliant rays of which the light is composed when the vapour has become luminous.

IX.

As the Moon and the planets have no light of their own, and only shine with the reflected light of the Sun, their spectrum must consequently resemble that of the Sun, modified only by the passage of the light through the atmospheres of the planets or by the reflexion on their surface.

The spectrum of the Moon does not indicate that our satellite is surrounded by any atmosphere, nor any other distinctive feature. In that of Jupiter there is a dark band corresponding to certain atmospheric terrestrial rays, and indicating therefore the presence of vapours similar to those in our own atmosphere. Another band denotes the presence of certain gases and vapours which do not exist there. The spectrum of Saturn is somewhat faint, but it contains certain rays similar to those in the spectrum of Jupiter.

M. Janssen ascertained that many of the atmospheric rays are produced by vapour of water, and it is probable that this aqueous vapour does exist in the atmospheres of Jupiter and Saturn. He goes on to say:—"During my recent mission to Italy and Greece, I took observations of several planets in regard to this point, notably from the summit of Etna, where the influence of the atmosphere is almost nullified. These observations, and some subsequent ones, made with the most powerful instruments, indicate the presence of vapour of water in the atmospheres of Mars and Saturn, thus adding a new and important feature to the already close analogies which connect the planets of our system. So we see that all these planets form as it were one family, circulating around one focus, which distributes amongst them heat and light. Each of them has its year, its seasons, its atmosphere, and many of them are known to contain clouds within their atmosphere.

"And, in addition, water, which is so important an element in the economy of every organism, is also common to them. These facts give us strong ground for supposing that life is not the exclusive privilege of our little Earth, herself but one of the younger sisters in the great family of planets!" *

Certain rose-tinted groups have been remarked in the spectrum of Mars, which may have some connection with the red hue distinctive of this planet.

The spectrum of Venus does not show any additional ray to denote the presence of an atmosphere. The absence of these rays may perhaps arise from the fact that the light is probably reflected, not by the surface of the planet, but by clouds some height above it.

X.

The stars, though much farther from us than the Moon and the planets, possessing, as they do, their own source of

* Memoir read to the *Académie des Sciences.*

light, furnish us with more detailed information as to the nature of the elements of which they are constituted.

Until the secret of spectrum analysis was discovered, we knew nothing about the stars, beyond the fact of their immeasurable distance, and their striking beauty; now, we are in a position to learn some details of their real character.

Spectrum observations tell us that the stars resemble the Sun, as to the general character of their composition. Their light, like that of the Sun, emanates from a matter raised to an intense white heat, and traverses an atmosphere of absorbing vapours. Yet, notwithstanding this structural unity, each star differs from the other, though not to an essential degree, in its chemical composition. Judging them by their spectra, they may be divided into four perfectly distinct types, though a few of the spectra, instead of belonging to one of these four categories, seem to be intermediate between them.* With a few exceptions, the terrestrial elements which are most largely distributed amongst the stars are precisely those which are essential to life as it is on the Earth, such as hydrogen, sodium, magnesium, and iron. The hydrogen, sodium, and magnesium also represent the ocean, which is an essential part of a world constituted as the Earth is.

Looking at the stars generally, they seem brilliant, like colourless diamonds, red, orange, or yellow tinted; but this is not so if they are carefully watched, or observed through a glass, for then we can see next to the red or orange-tinted stars others of a blue, green, or purple colour. The spectrum analysis shows us that these diverse colours are produced by the vapours in suspense in their atmospheres, and we know that the composition of a stellar

* Father Secchi on *The Sun*, p. 300.

atmosphere is in turn dependent upon the elements which constitute the star, and upon its temperature.

Spectrum analysis of the variable transient stars also reveals to us the phenomena produced by the incessant changes that react upon the rays which these stars transmit to us. Thus it is that we have received tidings of the great perturbations taking place in the brilliant star Corona, which was only recently observed, and which has already decreased in brilliancy.

XI.

During the last 150 years astronomers have been constantly revolving in their minds the veritable nature of the slightly luminous nebulosities (*nebulæ*) which stand out from the dark surface of the firmament—conglomerations so filmy in substance as to remind one of the comets. This question has become all the more interesting now that they are held to be a part of original matter—embryo stars.

The telescope has failed to enlighten us on this head, though it is true that since the object glasses have been made larger, many of these bodies have turned out to be actual stars. But at the same time other nebulosities, hitherto undiscovered, have been brought within the field of vision, to say nothing of other fantastic figures (aggregations of diffused light), which it is impossible to look upon as the produce of the combined brilliancy of countless suns situated at distances more or less unfathomable.

Spectrum analysis has settled this long-vexed question; has shown us that certain nebulæ were not masses of distinct stars, but matter in a gaseous state, and has even enabled us to ascertain their elements.

Mr. Huggins, describing his first experiment on this head, in August, 1864, says:—"I selected one of the luminaries in the class of nebulæ, which was very small, but relatively brilliant. Great was my astonishment when, on looking through the small glass of the spectrum apparatus, I discovered that its spectrum had no longer the appearance of a luminous coloured band such as a star would have produced, and that in place of the continuous band there was nothing to be seen but three bright rays, isolated from each other."

This spectrum must, so far as it was possible to judge, have proceeded from a light emitted by matter in a gaseous state. The most brilliant of its rays was produced by a body analogous to nitrogen, or, as Mr. Huggins thinks, even more elementary than nitrogen, and which we have not as yet been able to analyse. The weakest of its rays corresponded with the green of hydrogen. The mean ray of the group was almost, but not quite, identical with the ray of barium.

In addition to these brilliant rays, there was a continuous spectrum, singularly faint, proceeding from a diffused light, which seems to correspond with the centre of the nebula. This is proof that it contains a nucleus, very small, but more brilliant than the rest of its mass.

Mr. Huggins has since analysed the spectra of more than sixty nebulæ or stellar masses, which may be divided into two groups; the first comprising the nebulæ, which give a spectrum such as that just described, or, at all events, a spectrum comprising one or two of the three rays in question. Of the sixty which he examined, about a third belong to the class of gaseous bodies: the light of the remaining forty produces spectra of *apparent continuity.*

The harmony between the results of spectrosocpic and telescopic observations, in regard to what is common to both, is a proof of their accuracy; half of the nebulæ with a continuous spectrum have been shown to be stars, and in process of time another third will probably be added to the number. But Lord Rosse failed to ascertain this definitely concerning a single one of the gaseous nebulæ.

XII.

Mr. Huggins was the first to apply the spectrum analysis to the study, not of matter, but of the motion of the stars. If they possess any motion of relative importance, their rays must undergo a certain amount of displacement, and by this means these motions may be estimated. In respect to some stars, Sirius in particular, his researches have established the motion of these rays beyond all doubt.

He also applied this effective procedure of analysis to the observation of the comets, and arrived at the strange conclusion that the central part has a light of its own analogous to the flame of compound carburets, whereas the nebulosity emits only a light received from the Sun. This delicate distinction, says M. Faye, is of the highest importance in studying the physical constitution of these bodies. I may add that the spectrum expcriments conducted by Alexander Herschel have proved that sodium exists in a state of luminous vapour in the train of many aerolites.

The result of the spectrum studies goes, therefore, to prove that the stars only vary from each other, and from the Sun, in special and minor ways, and that there are no important and essential differences in their constitution. M. Faye, in one of his reports to the French Academy of

Sciences, says: "Thus we see extended to all the stars of the universe that unity of composition, which distinguishes our solar world and the aerolites; unity which is, however, compatible with many variations as singular as they are unlooked for."

These same results lend a great semblance of truth to the supposition that the stars have a function analogous to that of our Sun; and that they are, like it, surrounded by planets which they keep in place by force of attraction, and which they illumine and vivify by their light and heat. So it may well be—and eminent astronomers have given such an opinion their sanction—that these distant regions are inhabited by beings intelligent like ourselves, capable of studying the harmony of creation, and of appreciating the power of its supreme Author.

Fig. 14.—*Helios* (the Sun). Rhodes Medal in the British Museum.

CHAPTER IV.

THE SUN.

Its nature—Light and Aspect presented by its Surface—Grains of Rice, Willow-leaves, Straw-motes, &c.—Pores, Faculæ, and Spots in the Sun—Formation, nature, and motion of Spots—Rose-coloured Shadows, Red Protuberances—Change of Shape in the Spots—The Sun obfuscated by their enormous quantity—Rotation of the Sun—Synodical Revolution—Sidereal Revolution—Periodicity of the Spots—Solar Electricity and Hydrogen upon the Earth, and in the Planetary Regions—Solar Explosions—Constitution of the Sun—Two opposite hypotheses—Is the Sun inhabited?—Curious Anecdote—Recently acquired notions about the Sun—Temperature of the Sun—Curious Calculations—Is there any probability of the Sun ever ceasing to shed light, heat, and life upon the Earth—Lucretius and our modern Astronomers—Zodiacal Light: its nature—Some parts of the Sun more brilliant than others—Atmosphere of the Sun—Various elements of which the Sun is composed—The Seasons—Dimensions and distance of the Sun—Variation of its Diameter—Its influence upon the Earth—Recapitulation.

I.

"This star among the stars," to use Arago's expression—"the light of the world," as Copernicus calls it—"the heart of the universe," in the language of Theon of Smyrna—we see shining like a luminous globe, incessantly darting in every direction its rays, which transmit with inconceivable rapidity both light and heat.

Most of the ancient philosophers looked upon it as a burning body, which lighted the world with the emanation of its substances. In modern days there prevail two opinions, which I set forth in the chapter on Light; one being that the Sun does, as a matter of fact, emit luminous matter emanating from its own disc; the other, that space is filled with a rarefied and elastic substance, which is called ether. This substance, by the vibratory motions which it transmits with great rapidity, produces to the eye the phenomenon of light, much in the same way as the vibrations of the air produce to the ear that of sound. This latter theory is the one now universally adopted.

If the Sun's surface is examined through the powerful instruments which science has at command, it will be found to present the irregular and undulating appearance of a stormy sea, covered with crevices and hillocks, and dotted over with spots of a more or less dark colour. At times may be seen, particularly close to the edge of the spots, luminous masses, known as *faculæ.* To obtain a more complete knowledge of the Sun's structure, it must be examined through a powerful ocular glass, at a time when the atmosphere is perfectly still. Then it will be found that the surface is covered with a multitude of small grains, all of about the same dimensions, but varying very much in shape, though the majority of them are oval. A somewhat similar result is arrived at by examining through the microscope milk that has been standing some time, the globules of which have lost their regularity of shape. These grains sometimes unite in small groups, when they present a more brilliant appearance, while their oval shape has led to their being compared to grains of rice and willow leaves. The collections of these grains near the solar spots are somewhat different, for they seem to be longer, and to be joined to each other, perpendicularly to the edges of the penumbra, and look like straw-motes of unequal length, or the thatch on a roof seen through the telescope; the Sun also seems to be dotted with spots, of various shapes and size, less brilliant than the rest of its disc. They are simply solutions of continuity in the solar photosphere, caused by clouds composed of metallic vapours.

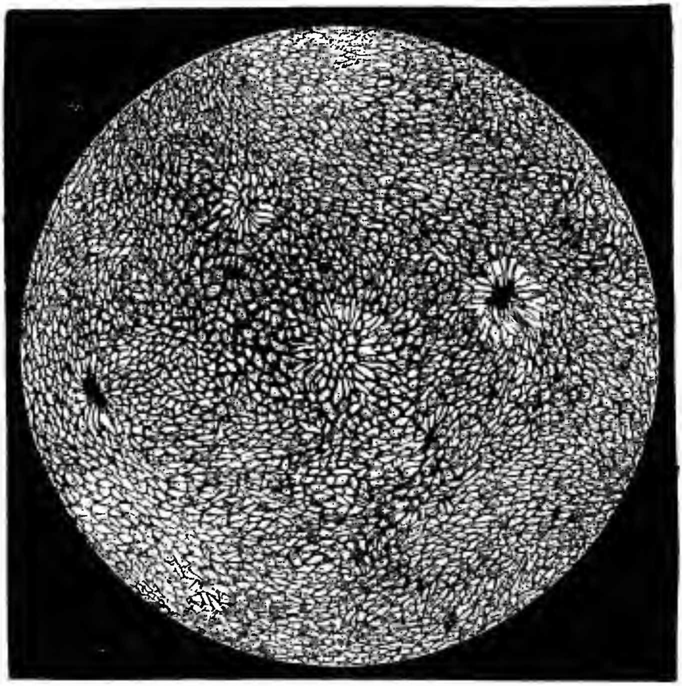


Fig. 15.—Appearance of the Sun's surface as seen through powerful glasses.

II.

The solar spots generally look like round black patches, though it often happens that they are clustered in such a way as to form an irregular figure, with the central part, which is called the *nucleus* or *umbra*, black; the contour, which is mezzo-tinto, is termed the *penumbra*, the whitish spots being known as faculæ.

These spots were at one time supposed to be satellites revolving round the Sun, and, subsequently, to be clouds floating in its atmosphere, and even masses of scoriæ floating

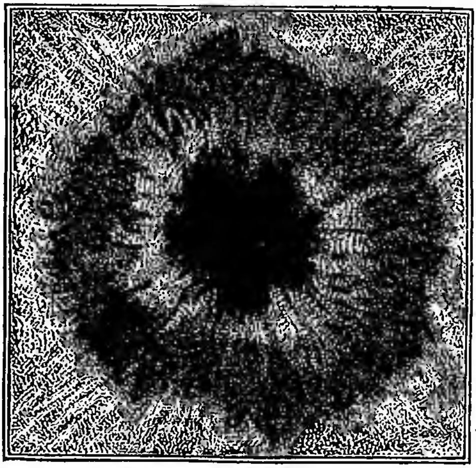


Fig. 16.—Front view of a spot on the Sun.

upon the sea of fire which constitutes its surface; or even mountains whose beetling flanks may have produced the phenomenon of the penumbra.

It is now about a century since Wilson (England) proved to demonstration that the spots were due to cavities of which he had been able to ascertain the precise depth; and he at the same time gave an exact idea as to the composition of the photosphere—that is to say, the luminous stratum which envelops the Sun.

The dimensions of the spots vary very much, some being mere black spots known as *pores,* others having a surface much larger than that of the Earth, some few being four or five times larger than the surface of our globe. The spots are not equally distributed all over the disc. There are not many in the immediate vicinity of the equator, and next to none in the latitudes exceeding 35 or 40

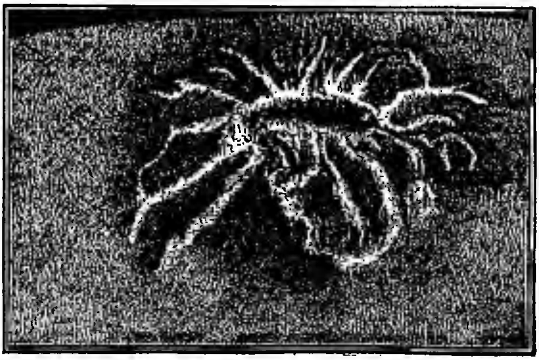


Fig. 17.—Spot observed close to the edge of the Sun.

degrees, but they are much more abundant in the two symmetrical zones comprised between 10 and 30 degrees of latitude.

Their number is also very variable; sometimes there are so many of them that in a single observation one can ascertain the zones which usually contain them. In 1637 they were so numerous that the heat and brilliancy of the Sun were perceptibly diminished, and history records many similar obfuscations brought about by the same cause. At other times they are so rare that a whole year passes away without one of them being seen. The phenomena which they present seem at times to have only a superficial influence, but, generally speaking, it extends to the depth of the solar body, which is often agitated and heaved up over a wide expanse, amounting occasionally to a quarter of the whole disc. Thus it is possible that these spots may be the outcome of a violent agitation amongst the matter of which the Sun is composed. The most plausible hypothesis is that attributing them to the influence of the planets (of Jupiter, Venus, and Mercury, in particular), the attraction of which create regular tides on the solar globe and the great disturbances already mentioned.

III.

Father Secchi, whose opinions, the result of most careful observation, are shared by many astronomers, looks upon them merely as solutions of continuity in the stratum of mists or luminous vapours which form the photosphere. These clouds differ from ours in two respects, being composed not of vapour of water, but of the vapour of metallic substances, and, by reason of their elevated temperature, they are luminous of themselves, but are less brilliant than photosphere. So far as the external aspect goes, it is the completely identical; the Earth covered with clouds, would appear mammiform in structure like the Sun to any one placed at some distance from it, and the phenomenon has even been remarked from mountain summits, especially during a thunderstorm.

This theory, as Father Secchi points out, explains, without having recourse to fabulous rates of speed, the rapidity with which certain changes in the shape of the spots take place. The apparent displacement of a cloud may be understood without supposing that the substance has traversed the same space as the contour of the cloud, for it may be accounted for by a change of temperature, producing upon the one hand condensation, upon the other, dissolution of the vapour over a considerable surface. He puts the question as to the nature of the spots in this way—"Are they caused by an obscure substance, rising above the luminous substance, or is it not rather the luminous matter which penetrates into an obscure region?"

He goes on to point out that all the phenomena alluded to are only to be explained by the second hypothesis: that there exists in the spots a luminous substance which penetrates into a less brilliant region—call the clouds an obscure part if you will, but it is none the less true that the luminous part penetrates thither. The spots must contain a transparent substance, less brilliant than the photosphere, and of a gaseous character. Our atmosphere would appear the same to a spectator looking into it from outside, say from the Moon; the clouds lighted up by the Sun would seem brilliant, while he would see black spots at the points where the air was transparent.*

M. Faye, of the French Institute, has, on the other hand, propounded the hypothesis that the spots are whirlwinds caused by the unequal speed of the successive zones of the photosphere, the angular rotation of which diminishes in speed from the equator to the poles, and that their law of motion denotes at the same time their distribution over the solar surface. In a report read to the Académie des Sciences (Dec. 30th, 1872) he says that this is naturally the case, because these spots are neither more nor less than whirlwinds engendered directly in the photosphere by the unequal speed of its parallels. In another memoir, he indicates a very curious similitude between solar and terrestrial cyclones, the laws of these two orders of phenomena seeming almost identical.

In reality, Father Secchi's theory is not incompatible

* Father Secchi on *The Sun*, p. 77.

with that of M. Faye, for the former, in reply to the arguments quoted above, says—"The question as to whether the spots are whirlwinds is but of secondary importance, for, even admitting them to be so, the only cause by which they could be originated would be an eruption."*

IV.

The spots often change in shape and vanish after having appeared for a short time, or traverse the whole visible surface of the Sun, following a line oblique to the diurnal motion and the plane of the ecliptic, and reappearing in

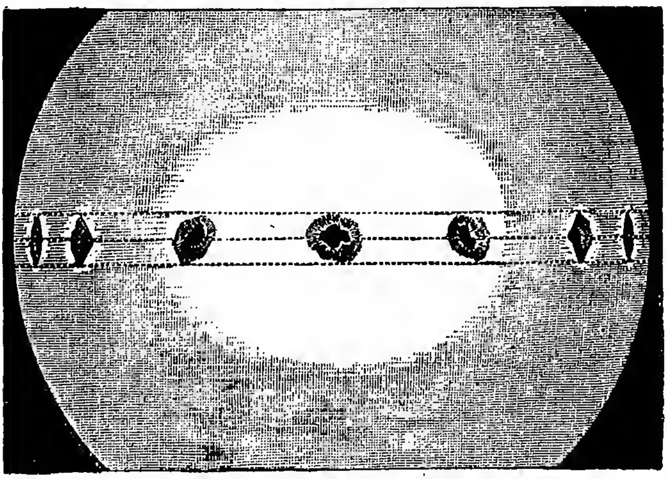


Fig. 18.—The same spot seen at different points of the Sun.

their original condition at the expiration of twelve or thirteen days.

The motion of these spots has revealed to us the remarkable phenomenon of the Sun's rotation upon itself.

Jordan Bruno, of Naples, author of a "Treatise upon

* Father Secchi's Memoir to the *Académie des Sciences,* March 3, 1873.

the Universe," published in 1591, was the first to suspect this fact, which was definitely ascertained to be correct by Jean Fabricius, from whose memoir, published in 1611, I quote the following passage:—"I conceived the idea of attracting the Sun's rays through a very small aperture to a darkened chamber on to a sheet of white paper. I noticed that this spot (one which Fabricius had discovered in the Sun) had taken the shape of an elongated cloud. After an interruption of three days, caused by the bad weather, my observations showed me that the spot had made an oblique movement westward. I also noticed a smaller one close to the edge of the Sun, which in a few days reached its centre, and after that a third. The first of the three soon disappeared, and the others at an interval of two or three days.

"I was apprehensive that they might not return, but at the end of ten days the first one reappeared in the east. It then became clear to me that these spots were accomplishing a revolution, and my opinion was confirmed by other persons to whom I pointed them out. I hesitated for some time to publish my observations, the accuracy of which seemed affected by the fact that these spots did not maintain the same distances from one another, and that they underwent a change of shape and speed. It was, therefore, all the more gratifying for me to remember that, as the spots are apparently on the actual body of the Sun, which is spherical and solid, they must necessarily diminish in size and slacken their speed as they reach its edges." *

From a close observation of the spots it has been concluded that the Sun revolves upon itself in a period of about twenty-five days, and like the Earth from east to west. Scheiner puts the *synodical,* that is to say, the apparent

* Fabricius, translated by Lalande.

revolution, in which the spot seems to an observer to return to the same point upon the disc, at twenty-seven days. This gives twenty-five days and a third for the duration of the *sidereal revolution*—that is to say, the time taken by a given point of the Sun to describe a complete circle. Thus, in place of observing the rotatory motion of the solar body itself, we are compelled to study that of its atmosphere, being, in fact, similarly placed to an astronomer who, to ascertain the rotatory motion of the Earth, had taken up his position in the Moon, with a cloud as his point of comparison. He would first of all have to study the atmospheric circulation and discover the laws by which it was governed —a task so difficult under such circumstances, as to be well-nigh impossible.*

V.

Schwabe has compiled a long series of statistics concerning the periodicity of the solar spots, having from 1826 to 1868 observed the Sun every day that the state of weather permitted. The result of his observations was that he recognised the existence of a positive periodicity, very marked maxima and minima succeeding each other at an interval of about ten years. This decennial period coincides very unexpectedly with several meteorological phenomena on the earth,—amongst others, as recent observations testify, with the variations of magnetic force and the periodicity of auroræ boreales.

The periodicity of the spots indicates, as Father Secchi remarks, a periodicity in the solar activity, and the variations of this activity may well be communicated to the Earth,

* Father Secchi on *The Sun*, p. 111.

either by means of heat or some other channel as yet unknown, such, for instance, as electro-dynamic induction, thus producing upon our globe meteorological or electric phenomena.*

The theory expounded by M. Becquerel at the Académie des Sciences, in 1871, is in confirmation of this view. He maintains that all the causes which elicit electricity from the Earth's surface would be insufficient to supply the enormous quantities which are diffused in the planetary regions, and even in our atmosphere. He goes on to show that the hitherto unknown origin of this electricity can be none other than the Sun. The spots upon this luminary, some of them 40,000 miles in extent, seem to be the cavities from which the hydrogen and the various substances composing the solar atmosphere are emitted. Now, hydrogen conveys with it the positive electricity which becomes diffused in the planetary regions, permeating thence to the terrestrial atmosphere, and even to the earth itself. The matter which electricity carries with it suffices for its transmission, it having been proved that electricity has the property of becoming diffused in a void space if it has any accompanying matter. The phenomena of the polar aurora produced by electric discharge also prove, in M. Becquerel's opinion, the existence of gaseous matter in space, far beyond the bounds assigned to the terrestrial atmosphere, it being certain that these auroræ are at least 125 miles distant from the earth's surface.

M. Charles Sainte-Claire Deville points out that the facts adduced by M. Becquerel in support of the celestial origin of atmospheric electricity confirm his own hypothesis as to the celestial origin of the variations of atmospheric tempera-

* Father Secchi on *The Sun*, p. 330.

ture, and, especially, as to the influence which the periodical apparition of cosmical substances in the interplanetary regions may have upon these phenomena.

The following facts will fit in harmoniously at this point.

Signor Tacchini wrote from Palermo to the Académie des Sciences, that the aurora borealis of February 4th, 1872, was a phenomenon so extraordinary as to have few parallels in scientific annals, and that its apparition was accompanied by corresponding movements upon the surface of the Sun.

The bad weather prevented Signor Tacchini from taking spectrum observations on the 3rd and 4th of February, but he noticed, on the morning of the 5th, that the whole

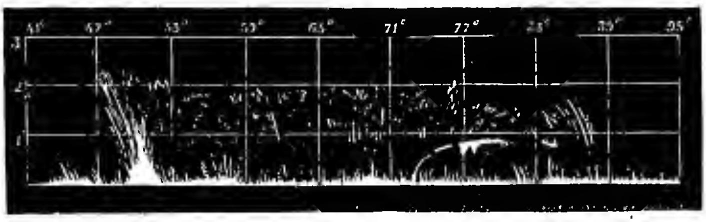


Fig. 19.—Motions noticed upon the Sun's surface by Signor Tacchini, during the aurora borealis of February 4th, 1872.

surface of the Sun was in an abnormal condition. The rim was covered with bright flames; towards the north pole they exceeded 20 seconds, with an arc of 36′ to right and to left, corresponding with a bright region of magnesium which, at the western rim, extended almost to the equator. In this portion, at 50 degrees from the pole, was seen a magnificent prominence, which rose to 2′ 40″, and from this point, at an arc of 40 degrees, the rim was lighted with brilliant flames, while the atmosphere was studded with small luminous filaments, or bright specks, about 2 minutes in height.

Signor Tacchini also sent a drawing to illustrate these phenomena (see fig. 19).

M. Cheux, communicating to the Académie des Sciences the features of a white aurora borealis observed near Angers, on the 8th of August, 1872, states that the Sun had been for some time in a very effervescent state, and that on examining it with a Foucault telescope on the 9th of August, he saw about 24 spots, one of which, a deep black, was very beautiful. The drawing which accompanied his description is reproduced in fig. 22, p. 88.

Senor Capello, of Lisbon, also sent some drawings of the Sun as it appeared on the 8th, 9th, 10th, and 11th of August, after the same aurora borealis (see figs. 23–26, p. 94).

Father Sanna-Solaro, in a memoir on the same subject, argued that if the Sun is taken to be the principal source of atmospheric electricity, the facts, otherwise most difficult to co-ordinate, immediately link themselves into the chain of phenomena, conveying with them, so to speak, their own explanation. Father Sanna-Solaro is, in my opinion, one of the highest authorities on meteorological subjects, and his work upon the " Causes and Laws of the Movements in the Atmosphere " may be studied with profit.

VI.

At the same time, there is anything but an unanimity of opinion as to whether the Sun is the main cause of the electricity by which we are surrounded. M. Faye, in a very able treatise in support of his own theory, says: " We know that there is a fundamental difference between electricity and heat or light. The greater the vacuum the more rapid is the propagation of light and heat, so much so that certain specialists, supposing a material medium to be necessary, propounded the idea of filling the infinity of space with absolutely imponderable ether. But electricity requires ponderable matter in order to manifest itself in the shape of currents or of simple force, attractive or repulsive. Electric experiments carried on in a place where there is an approach to a void, are very feeble in their results, and they come to a full stop in a laboratory where a complete void has been created. Thus, I repeat, the electric agencies in question must be conducted in a ponderable space. Now, we have seen that if the celestial regions are furrowed in all directions by numberless corpuscles, shooting stars, aerolites, remains of comets, and even, perhaps, by solar hydrogen, etc., these small masses of ponderable matter, accomplishing their distinct orbits round the Sun, could not possibly form a continuous mean like the air in which we set electricity into action.

"I should not have thought it necessary to insist upon this idea, but that my colleague, M. Becquerel, had recently brought it into prominence by his endeavour to connect the Sun with our own atmospheric electricity. M. Becquerel admits that the solar mass is incessantly emitting hydrogen which becomes diffused in space, conveying with it its own electricity, essentially positive, and communicating it to the stars on its passage, without, however, coming in contact with their atmospheres. I do not intend to discuss these ideas, merely wishing to point out that the hydrogenous emanations of the Sun would not constitute a continuous mean capable of serving as a vehicle of communication to electric repulsions or attractions. Repulsed from the Sun by the supposed electricity of the chromosphere, or rather, perhaps, by the repulsive force of the photosphere, these molecules would also be endowed with rotatory speed; they would, therefore, describe hyperbolic curves convex towards the Sun, and branching towards all parts of the universe. Thus they would speed along in separate directions, gradually getting further from each other, without being capable of exercising the mutual reactions which constitute an electric mean or a gas."*

M. Becquerel still maintains his theory that the Sun is the probable origin of electricity, and has answered M. Faye's arguments in a treatise laid before the Académie des Sciences, in November, 1872.

VII.

Before proceeding further, it will be as well to explain what is meant by the solar atmosphere, and the phenomena to which it gives rise. This atmosphere is double; the first part, which envelops the centre of the Sun, is called the *photosphere.* Like the region which it surrounds, it is the seat of vast chemical processes. As it radiates towards the celestial regions it loses a portion of its heat, while the gaseous bodies which it contains, becoming cool and condensing into vapour, relapse into the interior of the Sun, to return afresh into the photosphere, and recommence the same transformation. Such is the explanation given of the first atmosphere by those who are of opinion that the Sun has no solid nucleus—an opinion which is generally accepted in the present day, and the reasons for and against which will be found below.

The solar photosphere, according to Father Secchi,† must

* M. Faye, and the *Académie des Sciences*, Oct. 9th, 1872.

† Father Secchi on *The Sun*, p. 219.

contain vapours of every variety, which, owing to their extreme levity, must attain a great altitude. If a large number of bodies, looked upon by mineralogists as elementary —precious metals in particular—have not been discovered in the Sun, it does not follow that there are none, for it may well be that these metals, owing to the great density of their vapours, are detained in profound regions inaccessible to spectrum analysis. The following is the nomenclature given to substances known to exist in the Sun, arranging them in the order of their atomic weight, from the lighter to the heavier:—*hydrogen, sodium, magnesium, aluminium, silicon, potassium, calcium, chromium, manganese, iron, copper, zinc,* and *barium.*

Beyond this luminous envelope or photosphere, which forms the apparent limit of the solar disc, is an atmosphere properly so called, transparent, but endowed with a sufficient power of absorption to arrest a part of the solar rays. It is not of uniform altitude, attaining the maximum of height at the equator and near the spots, and the minimum at the poles.

This atmosphere, which completely envelops the Sun, is almost entirely composed of hydrogen of a very high temperature; it also contains a small quantity of sodium and magnesium vapour, and even of vapour of water. In it may be noticed aggregations of rose-hued patches, analogous to the flames which may be seen round the moon's disc during the solar eclipses, and which are known as *red protuberances.* Hydrogen is the main element of these phenomena.

VIII.

Father Secchi points out that, by virtue of the law of superficies, the inner strata of the sun must have a rotatory motion more rapid than the outer ones, and that the friction has not perhaps set up a motion of identical character throughout the whole mass. The points situated at the equator must be vested with a speed greater than those nearer to the poles, as is proved by the motion of the spots. He admits, at the same time, that the exact theory of circulation in the solar mass is not yet completely solved, and that we must for the present put up with hypotheses on the subject.

It also results from his observations, that the length of the solar diameter is to be decided by the amount of activity of the sun itself, and that the diameter of the disc is least where the activity is greatest. This unlooked-for conclusion concords with the general comparisons that have been made between the length of the diameters and the number of the protuberances.*

The Sun is the seat of explosions which seem to be connected with the production of spots. Father Secchi has even succeeded in obtaining some definite information as to one of these phenomena, the results of which he laid before the Académie des Sciences (August 5th, 1872), accompanied by the drawing reproduced in figs. 20 and 21.

This phenomenon occurred at 3.30 p.m. on the 7th of July, 1872. At 2.40 p.m. there was nothing but a small luminous jet; the internal motions of the incandescent vapours were so intense that the luminous clouds were seen to change in shape in a moment; and at 4.15 p.m. they had

* *Académie des Sciences*, Sept. 9th, 1872.

reached an altitude ten times greater than the diameter of the Earth, or, in other words, of 79,000 miles. This

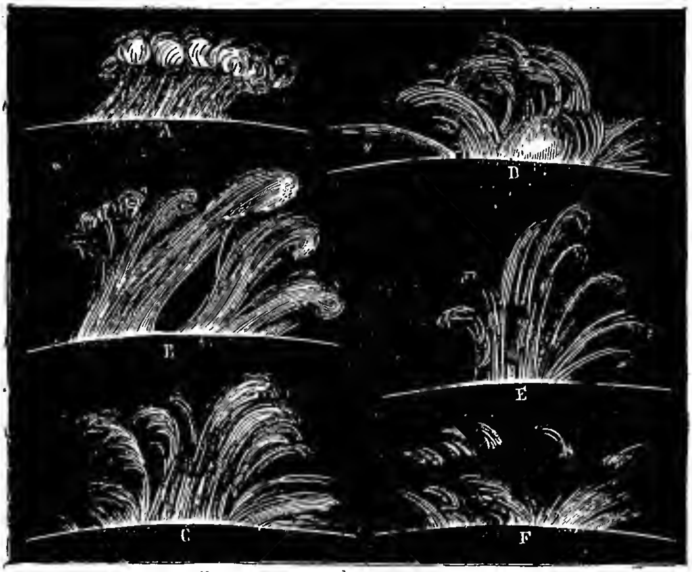


Fig. 20.—Solar explosions.

eruption lasted two hours, and was repeated the next day at the same point in the Sun. Father Secchi adds, that at the same date an Aurora Borealis was seen at Madrid and many other places in Europe, and the phenomenon was also accompanied by violent magnetic perturbations in many places.

The zodiacal light also extended over an unusually wide space, whence he concludes that these various phenomena are connected with each other, and that the great motions of the solar photosphere have their counterpart upon the earth. An examination of figs. 20 and 21 will show that the large cumulus-shaped cloud (A), which at 3.50 p.m. was just above the jets, was formed by the entanglement and fusion of the jets themselves, and that when the mass had risen and spread itself out, the cloud

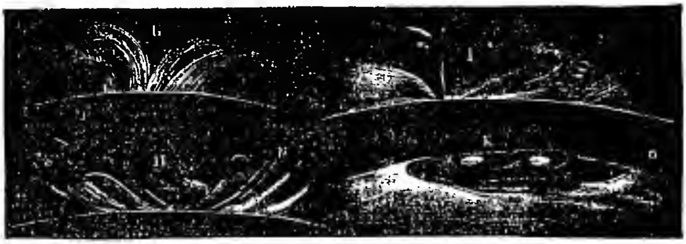


Fig. 21.—Solar explosions.

seemed to break up into filaments, curved in shape like the acanthus leaves of a Corinthian pillar (figs. B, C, D, E). At the same time, the curves of these jets are not only parabolic, but actually spiral, for the volute is seen to be forming at the extremities of the filaments. This fact, first pointed out by Young, has been confirmed beyond the possibility of a doubt during the eruption of July 13th (see fig. 21).

Fig. A represents the aspect of the strange phenomenon at 3.50 p.m., on the 7th of July; fig. B at 4.15; fig. C at 4.30; fig. D at 5.10; fig. F at 6.30. Fig. F represents the last traces of the eruption of the 7th, suspended in the air above some faint flames. Fig. G represents the eruption of July 13th, at 11.35 a.m.; fig. H at 4.35 p.m.; and fig. I at 6.20 p.m. Fig. K represents a spot displaying traces of the eruption observed upon the 11th of July near the Sun's edge.

IX.

The question as to how the Sun is constituted was considered by the most distinguished of astronomers long before the discovery of the spectrum analysis enabled the enquirer, seated in his study, to ascertain what was taking place millions and milliards of miles away, and the result naturally was that many diverse theories were propounded.

Herschel, Laplace, and several other astronomers of mark, held that the Sun consisted of an obscure body, surrounded by an atmosphere in which floated a deep stratum of clouds, and only the upper part of which was in ignition; whence it would follow that the Sun might be inhabited. This ingenious theory takes account of the various appearances presented by the spots with which the solar body is often studded, and acquires great probability from the polarizing experiments made by Arago. It has, however, been called in question of late years, chiefly owing to the results obtained from the spectrum analysis. If a flame containing metallic vapours is submitted to this analysis, their presence is denoted by characteristic coloured rays; but if behind this flame is a second luminous source more intense than the first, and containing the same metallic vapours, instead of the superposed rays receiving an accretion of brilliancy, the rays of the fainter focus will absorb those emanating from the more ardent one, and in the place of luminous there will be obscure rays. And, as the solar rays emit precisely similar beams, and give what is technically termed an *inverse* or *reversed* spectrum, Kirchoff has concluded that the body of the Sun must be more incandescent than its atmosphere.

But M. Petit, a former director of the Toulouse Observatory, in a memoir communicated to the Académie des Sciences, points out that this theory takes no account either of the spots, penumbræ, faculæ or luculæ, or of the absence of polarization. And as the total eclipses of the Sun have recently revealed that the photosphere is surrounded by a second aeriform envelope, luminous like the first, though in a minor degree, he very justly says that the inverse spectrum of the sun is easily to be explained, if we suppose that the second atmosphere contains metallic vapours of the same nature as those in the first. He concludes, therefore, that it is not necessary to admit that the solar nucleus is in a state of fusion, and Herschel's opinion as to the possibility of the Sun being inhabited need not be called in question. He adds, "Instead of an incandescent body, which must in the nature of things become cool and die out, we might thus imagine an incessant revivifying of the combustible properties, by organised beings inhabiting the surface of the solar nucleus, and maintaining the equilibrium, just as the plants and animals do in our own atmosphere."

Arago says, "If I were asked the simple question—'Is the Sun inhabited?' I should reply that I did not know. But if I were asked whether the Sun is habitable for beings organised like ourselves, I should have no hesitation in answering in the affirmative. The existence in the Sun of an obscure central nucleus, enveloped in an opaque atmosphere, separated by a considerable space from a luminous atmosphere, is by no means inconsistent with such a supposition. Herschel believed that the Sun was inhabited. He maintained that if the solar atmosphere, in which the luminous chemical reaction takes place, is a million leagues deep, there is no reason why the brilliancy should anywhere exceed that of an ordinary Aurora Borealis. The arguments upon which he relied as proof that the solar nucleus is not necessarily very hot, notwithstanding the incandescence of the atmosphere, are neither the only nor the most powerful ones that might be adduced. The direct observation, taken by Father Secchi, as to the lessened temperature of those points on the solar disc where the spots are noticed, is, in regard to this fact, of more importance than all the theoretical arguments put together. Dr. Elliott asserted, as early as 1787, that the sunlight was given by what he called a dense and universal Aurora Borealis, and he held, with the ancient philosophers, that the Sun might be inhabited. When he was tried at the Old Bailey for the murder of Miss Boydell, his friends—Dr. Simon amongst others—declared that he was out of his mind, and cited as a clear proof of his insanity the pages in which the opinions just quoted were embodied. The ideas of a madman are nearly always adopted. This anecdote seems fitted to figure in the annals of science, and I have taken it from 'Brewster's Encyclopædia.' "*

X.

The astronomers of the present day are less unanimous than they were in Arago's time as to the possibility of the Sun being inhabited; but M. Vicaire, in a communication to the Académie des Sciences, endeavours to show that we must go back to the theory of Wilson, Herschel, and Arago, as to the existence, within the photosphere, of a nucleus comparatively cool and obscure.

To use his own language: "The principal objection that has been advanced against the hypothesis is that this nucleus, subject to the radiation of the photosphere, would long since have acquired the same temperature. This

* Arago's *Astronomie Populaire.*

objection falls to the ground if the heat received by this nucleus is employed in vaporizing the liquid of which it is formed. Moreover, this heat may and must be only a trifling fraction of what is emitted by the photosphere, absorbed as it is by the intermediate stratum, which is incessantly re-conducting it into the photosphere. As to the length of time that the nucleus has been subject to this volatilization, there is nothing to prove that it is to be measured by the total duration of the earth. I believe, on the contrary, that the sun, as at present constituted, has only shone upon this globe since the most recent geological periods."*

Many astronomers, Father Secchi and M. Faye among them, believe that the whole mass of the Sun is gaseous,

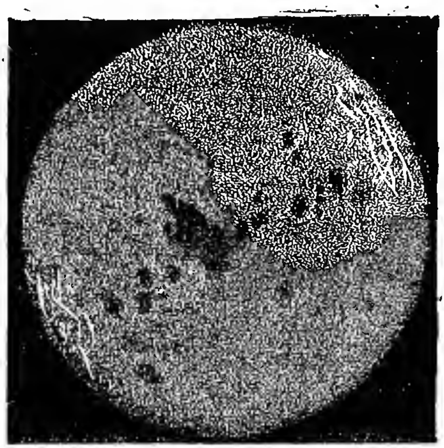


Fig. 22.—Surface of the Sun on the 9th of August, 1872, at 6 a.m., as observed by M. Cheux.

and that the speed of its various strata increases from the surface to the centre. The former says: "When the Sun

* *Académie des Sciences*, Aug. 26th, 1872.

at the epoch of its formation had reached a volume about equivalent to that which it now possesses, its temperature would have been at least 500 million degrees, and, moreover, we know by experiments that even now its surface temperature amounts to several million degrees; that of the interior is probably higher still. We must conclude from these facts that the Sun cannot be composed of a solid mass; nor, enormous as may be the pressure existent in this mass, it cannot possibly, so to speak, be in a liquid state. Whence we are necessarily led to the supposition that it is gaseous, notwithstanding its extreme condensation."*

M. Delaunay, of the Institute, says: "The enormous temperature which the Sun must possess, renders very probable the existence in its atmosphere of the various bodies just mentioned (different metals). Upon the other hand, as the volume of the Sun is 1,260,000 times that of the terrestrial globe, and as its mass is only 314,760 times that of the Earth, the mean density of the Sun is only a quarter that of the Earth, and consequently not much greater than that of water. Such being the case, it is difficult to believe that the Sun is a solid body enveloped in a covering of brilliant clouds, constituting what is termed the *photosphere*. I am inclined, rather, to agree with M. Faye, that the Sun is a gaseous mass with a very elevated temperature, which prevents the elementary substances that enter into its composition from consolidating; while their decrease in heat superficially, brought about by the radiation into the celestial spaces beyond, would facilitate the production of combinations, which in turn, owing to the formation of solid and pulverulent precipitates, disseminated

* Father Secchi on *The Sun*, p. 289.

in the outer strata of the gaseous mass, would produce the brilliant light of the photosphere. These solid precipitates would, by reason of their greater density, gradually descend into the inner portion of the mass, where they would be decomposed by the high temperature and again become gaseous. Moreover, these descending currents would cause the formation of ascending currents, by means of which the matters in the inner part would be brought to the surface, so that the whole gaseous mass would in this way contribute to sustain the vast production of heat and light upon the Sun's surface. The spots, varying in number, position, shape, and size, which are generally visible in the Sun, would merely be gaps accidentally made, amidst the refulgent clouds of the photosphere, by the currents alluded to above."*

For my own part, after comparing the various solutions that have been proposed, I must pronounce for the gaseous nature of the Sun.

XI.

In a letter to M. Dumas, which was read at the Académie des Sciences, in the early part of 1869, M. Janssen, whose researches in connexion with the spectrum analysis have obtained great notoriety, supports this view by a summary of the knowledge hitherto acquired as to the constitution of the Sun. This communication, stated succinctly, shows that modern research, interpreted by M. Faye's theory, tends to the conclusion that the Sun is essentially a gaseous globe, with a temperature of its own so elevated that no

* Delaunay's *Notice sur l'Analyse Spectrale.*

substance or body can exist there, save in a very gasiform state. But it is known that gases, even when raised to a very high temperature, are but faintly luminous when they do not contain particles of a fixed body—that is to say, of one not reduced to gas. How, then, are we to explain the brilliancy of the Sun? In this way. The region in which the solar globe moves causes a diminution of temperature upon the surface of that luminary, sufficient to condense within it the gaseous elements and reduce them into solid dust. This dust, mixed up with the incandescent gases, gives them the effulgency and radiation which we perceive, just as carbon, lime, and magnesium impart the luminous property to the dull flames of our own gases.

Thus, by a relative decline of temperature, the gaseous globe is surrounded by a very luminous envelope; this is the photosphere, or visible part of the Sun—the Sun itself as it appears to the general public. In this photosphere are visible spots and rents which have attracted the careful attention of astronomers. These rents in the luminous envelope, the diameter of which is often double or treble that of the earth, enable us to ascertain that the central gaseous nucleus is relatively obscure; their motions have revealed the law of the superficial rotation of the Sun—a rotation, the speed of which varies according to the latitudes, and thus have supplied us with one of the most striking proofs of the gaseous character of the Sun.

It is the examination of the spots, too, that has led astronomers to admit the existence of an atmosphere around the luminous envelope. But the existence of this atmosphere, which has since been revealed by the phenomena of refraction noticed on the photosphere, and by the effects of absorption remarked upon the edges of the solar disc, was only guessed at, and its nature, its altitude, and its composition were the objects of the most contradictory statements. As to those singular luminous appendages or protuberances which have been observed during the latest total eclipses, absolutely nothing was known about them. Such was the state of things when the great eclipse of August 18th, 1868, supplied the first opportunity for applying the new method of analysis to these phenomena.

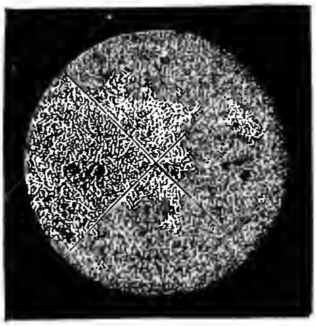
Analysis of the light of these protuberances revealed first of all their character and their gaseous composition. These large appendages are almost exclusively composed of incandescent hydrogen. It has also been remarked that this hydrogen exists over the whole circumference of the Sun, and that the protuberances are but the more prominent parts of this hydrogenic atmosphere.

When this interesting memoir, here summarized, was read, M. Leverrier remarked that the theory which consisted in treating the Sun, in regard to its luminous portion, as an incandescent globe, covered with a small gaseous atmosphere, to which part of the phenomena observed upon its surface are attributable, has been established beyond the possibility of doubt by the observations taken during the total eclipse of 1860. The important point ascertained during the eclipse of 1868 is as to the nature of this atmosphere; and M. Janssen, by making it possible to observe, at any period, phenomena which had before been visible only at the moment of a general eclipse, had rendered a great service to science. Upon the same occasion, M. Leverrier read a memoir from M. Royet, in which it is shown that the yellow ray discovered by the spectrum analysis is visible upon the whole contour of the Sun; whence he concludes that the incandescent gas to which it corresponds is, upon the same principle as hydrogen, a constitutive element of the solar atmosphere. At the same time, we do not at present know what this gas is, for the ray in question does not coincide with the yellow ray of sodium.

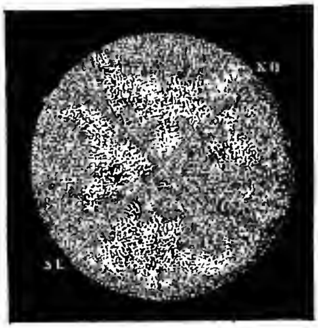
XII.

The question naturally arises: Why is the temperature of the Sun so enormous? It may have been caused by the very force of the gravity which conjoined the elements that formed the central point of the solar system. In the first instance, the temperature thus mechanically acquired must have been much higher than it is at present, now that the Sun is getting cooler. At the same time, the diminution of its heat, great as it may be, is almost imperceptible to us, being, as it is, so gradual, and partially compensated by the transforming of a portion of the solar mass into various chemical combinations. It may also be that certain foreign bodies, attracted into the Sun, help to maintain its incessant combustion. There is a great variety of opinion as to the sum of the solar temperature, and it is very astonishing to find that the researches of the specialists lead them to such widely different conclusions. During the last few years much has been written upon this subject, and one of the most recent treatises is that of M. Vicaire, who points out that Father Secchi estimates the temperature at 10,000,000 degrees Cent., while M. Spœrer puts it at not more than 37,000. And if to these opinions I add that of M. Pouillet, who thinks that it is not less than 1,461, or more than 1,761 degrees, my readers will see that science has not yet reached any satisfactory conclusion in regard to this matter.

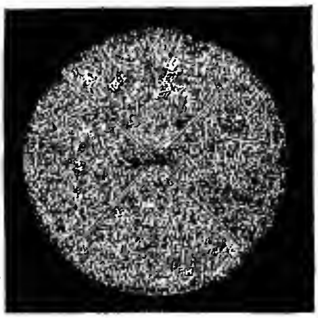
It is even more surprising that the most opposite results, those of Secchi and of Pouillet, have been deduced from the same phenomenon, viz., the calorific radiation of the Sun, the intensity of which they estimated by an almost identical process. As M. Vicaire remarks, so enormous a difference



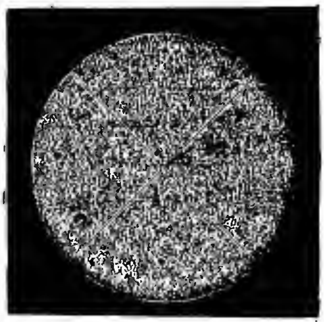
August 8th, 7h. 29m. p.m.



August 9th, 7h. 15m. p.m.



August 10th, 8h. 5m. p.m.



August 11th, 9h. 42m. p.m.

Figs. 22A to 25.—Aspects of the Sun during the Aurora Borealis of August, 1872.

in the results evidently cannot be due to the observations, but to the manner in which they have been interpreted; and, after careful consideration, he arrives at the conclusion that Pouillet's evaluation is far nearer the truth than that of Father Secchi. Upon this, M. Elie de Beaumont pointed out how Sir William Thomson had shown that the Sun's temperature cannot be so very much higher than that attained in certain manufacturing processes, and adverted to his treatise upon solar heat, in which he states that the quantity emitted, according to Pouillet, is not equal to more than a seven-thousand horse power to each square foot of its surface. Coal burnt at the rate of a pound in two seconds would produce almost the same result, and Rankine has estimated that in the locomotives coal is consumed at a rate not greater than a pound per square foot in from thirty to ninety seconds.

This great problem as to the surface temperature of the Sun is, as M. Elie de Beaumont adds, more accessible now than it once was. This is principally due to the astronomical expeditions for studying, at the epoch of total eclipses, the physical constitution of the Sun, not the least important of which was that of 1858 to Panaragua in Brazil.

The result of M. Becquerel's researches in regard to the question of high temperatures, and the phenomena of irradiation which accompany them, leads him to the conclusion that the highest temperatures which can be produced by combustion or electric agency do not exceed 2000 or 2500 degrees Cent., and that consequently the solar temperature, which is not so widely removed as might be supposed from the temperatures of these sources, would not exceed 3000 degrees.

M. Fizeau thinks that if the solar radiation is, as a matter of fact, greater than the most intense sources of light which the Earth can produce, it has not, nevertheless, been found more than double or treble that of the light proceeding from them all. Thus these two sources or light are in all points comparable, whence it is to be inferred that their respective temperatures cannot differ very widely, as certain estimates recently formed about the temperature of the solar surface would tend to prove. M. Fizeau's argument seems to me very conclusive.

M. H. Sainte-Claire Deville says, that to speak of very elevated temperatures and their measurement is to admit that the gases are capable of dilation or compression by heat to an indefinite extent—a fact which is not proved; or else that there is no limit to the chemical combinations, of which there is even less evidence. He also points out that to calculate the temperature of any given point of the Sun's mass is to neglect altogether the influence of the stratum—a very deep one, for all we know—of obscure solar matter which, so far as we can judge, overspreads the incandescent stratum, and the radiation of which towards the Earth is also eliminated. He goes on to notice a fresh experiment which might help to settle the question. The hydrogen rays emitted by certain points of the Sun's incandescent matter, have been ascertained by astronomical observations; Frankland and Lockyer found them present in hydrogen flame subjected to a certain pressure, and it follows that the combustible temperature of hydrogen at this same pressure can be calculated, and, as a necessary consequence, the character and pressure of the gases at those points of the solar atmosphere where the hydrogen rays have been noticed. The result of the first experiments upon this head induce him to believe that the temperature is somewhere about 2500 or 2800 degrees, which corresponds with the subsequent experiments of Bunsen and Debray.

XIII.

To complete this summary of the opinions arrived at by the most eminent astronomers, I will now add the conclusions come to by Father Secchi concerning solar temperature, its origin, and its sustenance.

1st. The solar temperature is of several million degrees, though it is impossible to say precisely how many.*

2nd. This temperature is to all appearances the result of gravity, and must have been produced by the collapse of the matter which constituted the primitive nebula and which now composes the Sun and the planets.

3rd. At this epoch of formation the temperature must have been much higher than it now is: therefore the Sun is in process of cooling.

4th. Though the Sun is continually losing vast quantities of heat, the diminution of temperature is almost imperceptible, not exceeding one degree in four thousand years. This is due to the state of disjunction in which the matter remains under the action of the heat.

5th. Though the temperature of the Sun is not altogether invariable, its secular variations are, at the same time, slighter than the frequent fluctuations which we remark without being able to investigate them completely. Therefore we may take for granted that our planet will continue to be habitable for a long series of ages.

He proceeds to say that "though the temperature of the Sun is not altogether invariable, yet the variations are so trifling that they are only perceptible after many thousands of years. After a still greater lapse of time—after many millions of centuries, for instance—the Sun will become much cooler; and a time will, no doubt, arrive when it will

* This estimate is, as mentioned above, very much contested.

no longer possess the property of sustaining life upon the surface of the planets. It is possible that the Creator has thus ordered things from the beginning, with the purpose of repairing its activity by some extraordinary phenomenon, such, for instance, as the fall of a nebula. But these are points upon which it is unnecessary for us to dwell. Who can say whether the order which now reigns in our solar system is intended to last indefinitely? As we know from geology, the present state of things has not always been going on, and as it has had a beginning, why should it not have an end?" *

XIV.

Lucretius forestalled our modern astronomers when he said: "I am aware how novel and incredible an opinion I express in predicting the future collapse of the Heavens and the Earth, and how difficult it will be for me to convince people of its truth. This is always the case when one propounds a truth to which utterance has not yet been given, and which, moreover, is not susceptible to the ear or the touch —the two sole conductors of evidence into the sanctuary of the human mind. . . . You believe, perhaps, that the Earth and the Sun, the Heavens and the Sea, the Moon and the Stars are divine substances, destined to be eternal; that it is, consequently, an act of impiety, equal to that of the Giants, and meriting the severest punishment, to dare by vain arguments to shake the vault of the world, to extinguish the Sun which shines in the heavens, and to subject immortal beings to destruction. But all these bodies are so far from having anything in common with the divine nature, and so unworthy to be placed in the rank of Gods, that they

* Father Secchi on *The Sun*, p. 292.

are rather calculated to give us an idea of brute and inanimate matter; for you must not suppose that feeling and intelligence are common to all bodies alike.

"Moreover, if the Heavens and the Earth have never had an origin, if they subsist since all eternity, how comes it that there was no poet to celebrate the achievements preceding the war of Thebes and the downfall of Troy? How is it that so many heroic deeds are buried in oblivion and excluded for ever from the eternal annals of fame? I am certain that our world is new; it is yet in its infancy, and its origin does not date far back. This is why certain arts are perfected and others only invented to-day; navigation is but just beginning to progress; the science of harmony is a discovery of our own time; and, lastly, that philosophy, the principles of which I expound, is but of recent date, and I am the first of my countrymen who has been able to discourse about it." *

This train of reasoning is not very conclusive, but the quotation just given expresses in beautiful language the ideas which were current upon this topic in the days of Lucretius.

To bring the subject of solar heat to a conclusion, I may add that researches about the Sun date from a very early period. Lucas Valerius remarked that its image was more brilliant at the centre than at the edges. This important fact was called in question by Galileo, but it is correct, as has been proved by recent observations, those of Father Secchi amongst others. The latter also show:—

1st. That all radiations undergo a considerable absorption, which increases from the centre of the solar disc to the edge, where it is at its maximum.

2nd. That the equatorial regions are of a higher tempe-

* Lucretius, Book iv.

rature than the regions situated beyond the 30th degree of latitude, the difference being at least 1-16.

3rd. That the temperature is a trifle higher in the Northern than it is in the Southern hemispheres.

4th. That just as the spots emit less light, so also do they emit less heat than the other regions.*

XV.

This is the place for a few remarks concerning the zodiacal light. This light* is a phenomenon which generally accompanies sunrise and sunset, about the period of the equinoxes, that of spring more especially; it is seen in the form of a cone of whitish light, which is visible in the direction of the zodiac, being brightest in the regions where the sky is very limpid. I have observed it, under specially favourable conditions, upon the Atlantic, and in the Southern Seas. In length it sometimes seems to describe an arc of ninety degrees.

The ancients designated this light by the name of *trabes* (rafter), The first savants who attempted to give it a scientific explanation seem to have been J. D. Cassini and Mairan. Cassini supposed the Sun to be enveloped in a nebulous stratum, in shape like a very flattened and nearly lenticular spheroid, extending beyond the orbits of Minerva and Venus to that of the Earth. De Mairan, who had even taken detailed observations of this phenomenon, gives a description of it corresponding to that of Humboldt, and, like Cassini, he also connects it with the solar atmosphere, higher around its equator, on account of its rotation, which would account for its elongated form, visible only when the points of observation are not plunged in this atmosphere.

* Father Secchi on *The Sun*, p. 133.

M. Liais, in the course of his numerous sea-voyages, devoted special attention to this phenomenon, and he communicated the result of his observations to the Académie des Sciences in 1858. "I have demonstrated," he says, "that one can only account for the zodiacal light by admitting that it is due to an imponderable substance forming around the Sun a sort of nebulosity, in which the Earth is completely plunged. The annular aspect of this nebulosity is caused by its forming a sort of flattened ellipsoid round the Sun, that is to say, a thin stratum of matter very slightly inclined towards the terrestrial orbit, which is entirely contained in the interior of this stratum. If, therefore, we look in the direction of the flattening, or, in other words, of the ecliptic, we remark a greater thickness of matter than exists in any other direction. Consequently, we receive more light from the side of the zodiac than we do from other quarters, so that this zone appears to us more luminous than the other parts of the sky, without being so in reality. Everybody must have remarked that when the weather is very clear no part of the celestial vault is completely sombre. Owing to the limpidity of the air, the light from the nadir is also more pronounced at the tropics than in the temperate regions. This comes from the solar nebula, to the glimmer of which is conjoined the slight quantity of light transmitted to us by the stars.

"The zodiacal light, when a good view can be got of it, as in the intertropical zone, is the most beautiful of all phenomena. In colour it is pure white, though, as seen in Europe, certain observers have thought that they could discern a reddish tint. This latter has not, however, any real existence; for if so it would be better seen at the tropics, as colouration always becomes more marked in

Fig. 26.—The Zodiacal Light in the tropical regions.

proportion to its intensity. I believe that observers have in this instance, confounded the zodiacal light with the last red traces of twilight. At the tropics themselves, in the months of July and August for that of Capricorn, and in the months of January and February for that of Cancer, the zodiacal light is visible in the evening after sunset, perpendicular to the horizon. When night sets fully in, there rises in the west a white vertical column, the central axis of which equals and even exceeds in intensity the most brilliant parts of the milky way. Upon the edges of this column the light gradually tones off to the faint glimmer of the heavens. It differs in this respect from the milky way, the edges of which at certain points present a striking contrast to the surrounding sky, as in the black aperture of the Southern Cross called the *coal-sack*."*

Silbermann deduces from the observations which he has made that the zodiacal light has close affinity with the affluence of shooting stars and the apparition of Auroræ Boreales. In a memoir communicated to the Académie des Sciences, he says: "Whenever there is an affluence of shooting stars, there is an Aurora Borealis, either luminous or else merely cloudy, in the mean latitudes. Numerous facts make me think that such is also the case with the zodiacal light, and this recalls to my mind that the zodiacal light, like the Auroræ, concurs with sudden oscillations of the barometer, and that it is sometimes also, like the Auroræ, of a bright red colour. . . . The sudden changes of intensity, as well as the appearance of undulatory motions, were observed by Humboldt. A zodiacal light, extending from one edge of the horizon to the other, like that seen by Béguelin, was observed by M. Liais.

* Liais, *Espace Céleste*, p. 131.

Respighi, again, has recently ascertained by spectrum analysis that the zodiacal light offers the brilliant ray of nitrogen discovered by Augtröm in the Auroræ Boreales. All these facts, as well as the coincidence of the zodiacal light with the affluences of shooting stars and the Auroræ Boreales, tend to show that this light is in reality a zodiacal Aurora, corresponding to the tide wave, and not to that of cosmical matter. It is known, too, that Laplace would not admit that the zodiacal light might be a wide extension of the Sun's atmosphere.*

XVI.

This notice would not be complete without a succinct summary of the scientific notions concerning the Sun which have now long been acquired and popularised in elementary works of education.

The Sun is incessantly darting its rays from all points of its surface, and there is not an instant during which its light ceases to permeate every corner of the universe.

From the close of June it undergoes a daily decrease of elevation, but the heat, nevertheless, continues to increase during the summer. And this is easy of comprehension, for we know that a body warmed by the Sun retains its heat for some time after it has ceased to be exposed to the solar rays. If a good-sized piece of metal is exposed to the Sun during a very hot summer day, it will be found to retain a certain amount of heat an hour after sunset. It therefore follows that the Earth, which is so much larger, will retain during the night, and even until the following morning, part of the heat communicated to it by the Sun on the previous

* *Académie des Sciences,* April 8th, 1872.

day. The Sun adds a fresh amount to that already existing, and so the Earth obtains an increasing balance of heat. In this way the heat goes on increasing in the bosom of the Earth, or in the air to which it communicates itself, until the nights get longer, when our globe gradually loses the heat which it had contracted during the summer.

The Sun is placed in the centre of our planetary system, the Earth revolving around it in the space of about 365 days 6 hours. Until the time of Copernicus it was generally believed that the Earth was motionless, the Sun revolving around it; but at that period people were ignorant as to the immense distance of the Sun from us, and of its real size (1,260,000 times larger than the Earth), so that they did not see any reason why it should not revolve around our planet.

How could it be possible for a body so enormous as the Sun to travel an orbit of 500,000,000 miles in twenty-four hours? The stars, immense globes, whose exact size we are unable to ascertain, would, to speak only of those that are least remote from us, have to travel 125,000,000 miles per second. And, lastly, how could the radiant globe of the Sun circulate around a body so small as the Earth without dragging it from its place, if it were united to it by invisible ties? Or, if the Sun were not attached to the Earth, would it not pursue its course in space, leaving our planet hopelessly in the rear?

If two stones tied together are thrown into the air they will be seen to circulate around a point comprised in the interval between them, and which is their common centre of gravity. If one is much heavier than the other, the centre of gravity will be proportionately nearer to the former, and may even be situated within it, in which case the small one will seem to circulate by itself around the larger one, which will only be slightly displaced. Physics teach us that the centre of gravity of two bodies is to be ascertained by dividing their mutual distance in inverse ratio to their weight or volume, and by means of this calculation we learn that the proportion of the Sun's mass to that of the Earth is as 354,936 is to 1. It follows, then, that the common centre of gravity of these two bodies is situated at 243 miles from the Sun's centre. The latter, therefore, does not move, the Earth revolving around it in the space of about 365 days, and turning upon its own axis every twenty-four hours. The first impression of our eyesight would of course lead us to suppose that the Sun and the other planets revolve round the Earth, and it is this illusion which led the ancient astronomers into error.

The Sun's distance from the Earth is about 91,430,000 miles; a cannon-ball travelling at the rate of 1,637½ miles an hour, or 39,750 a day, would take 6 years and 110 days to reach it. The Sun's diameter is 852,584 miles, or nearly four times the distance between us and the Moon. Its distance varies with the different seasons, and this is why the apparent diameter of the Sun is not always of the same dimensions. This remarkable phenomenon is occasioned by the translation of the Earth in an elliptic curve which brings us nearer to the Sun in summer than in winter; whence it is that the solar disc seems larger to us in the former than in the latter season.

Now if we compare the Sun with other bodies which people the immensity of space, we are taught by science that it is but an insignificant star amongst the countless legion of luminaries which shine before our eyes. This

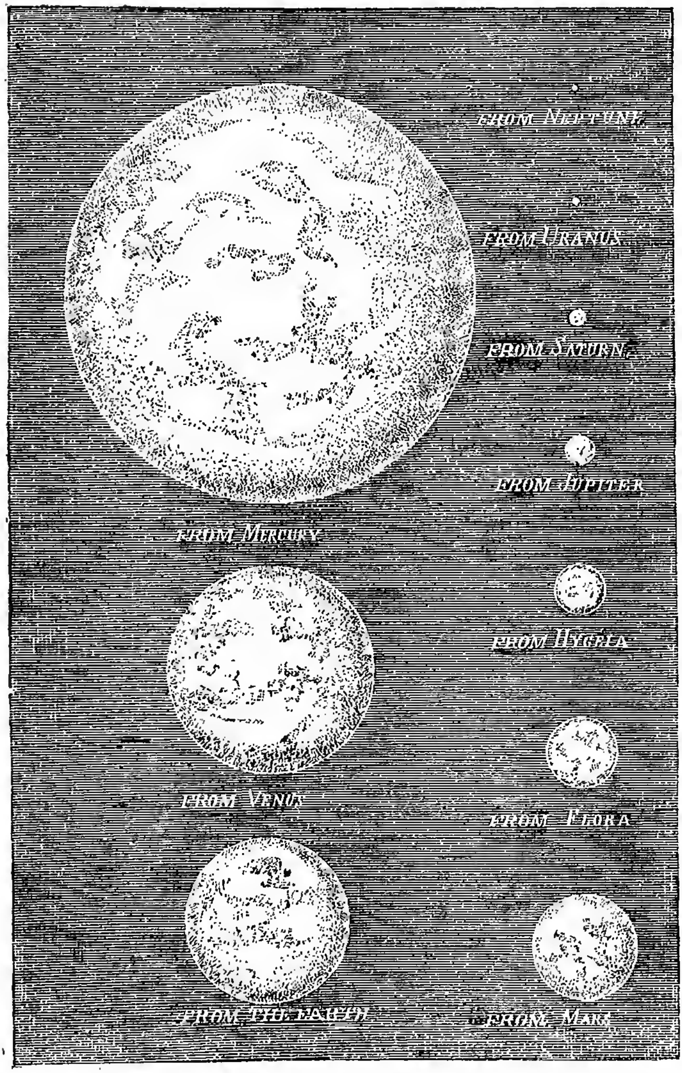


Fig. 27.—Proportional size of the Sun as seen from the different planets.

From Mercury.
,, Venus.
,, the Earth.

From Neptune.
,, Uranus.
,, Saturn.
, Jupiter.
,, Hygeia.
,, Flora.
,, Mars.

subject will be treated at greater length in the chapter on the stars.

XVII.

Not only is the Sun the centre around which the planets describe their orbits ; it is also their centre of life. Nothing can breathe or live without the beneficent influence of its rays. Lavoisier gave expression to this idea when he said, "Organism, feeling, spontaneous motion, and life, only exist upon the surface of the Earth and in regions exposed to the light. One might fancy that the fable of Prometheus was the expression of a philosophic truth which had not escaped the notice of our forefathers. Without light, nature was lifeless, dead, and inanimate. A beneficent Being, in providing the Earth's surface with light, endowed it with organism, feeling, and thought."

In my work upon the "Laws of Life,"* I dwelt at length upon the physiological influence of the agents of nature, a subject to which I can only allude casually in these pages.

Speaking generally, it may be said that the life of every creature is more perfect in proportion to the amount of light which it can command, and it even seems that life is not possible without its influence, for we meet with nothing but inorganic bodies in the entrails of the Earth, or in the deep caverns to which it cannot penetrate. In them is no breathing or sentient thing ; at most they contain certain kinds of mosses or lichens, which form the first and most imperfect phase of vegetation, and on minuter examination it is seen that most of these plants (if indeed they are plants) only grow upon or close to rotten timber. And even upon the

* *Les Lois de la Vie, et l'Art de prolonger ses Jours*, a work crowned by the French Academy (Firmin-Didot & Co.).

Earth's surface, if a vegetable or animal substance is deprived of daylight, it will successively lose its colour and vigour, then stop growing and become stunted, no matter how carefully it may be nurtured and tended.

Man himself, when deprived of light, becomes pale, enervated, decrepit, and eventually loses his energy, as is unhappily too clearly proved in the case of persons who have been confined for a long period in a dungeon, of miners, ship's stokers, workmen in badly-lighted factories, and the inhabitants of cellars or narrow streets. Heat, which, it may be, is only light in another form, is not less needful for life; it alone can develop the first germs of being. Heat begets life and life begets heat, an indissoluble bond connecting these two phenomena. It would, in fact, be difficult to say which of the two is cause and which effect; all we know is that wherever there is life, there also is, more or less, heat.

M. Radau, in an excellent work upon the subject, says that "the influence which the Sun exercises upon vegetation is greater than was formerly supposed to be the case. Not only does it supply the heat which hatches the germs deposited in the ground; it also fosters the respiration of the plants, and, in a certain degree, their growth. And as our alimentary and combustible substances proceed directly or by successive transformations from the vegetable kingdom, it may be said that they represent an amount of active power borrowed from the Sun in the shape of luminous vibrations, when the elements of which the plants are formed are in the act of grouping and combining together. The forces stored up by this gradual process of chemical affinities reappear, partially at least, in the mechanical efforts which the animal being is constantly making, and in the shape of which he expends a part of his own substance. They also reappear in the working of machines fed with coal. They are transformed into heat when wood is burned in a fire-place, or a nutritive substance burnt in the blood of a living thing which has the faculty of respiration, but not of motion. Thus it is that light, by making the plants to grow and flourish, prepares their nourishment for the inhabitants of the Earth, and provides them with an inexhaustible source of mechanical power."*

When winter has plunged nature into apparent death, the mild temperature of spring is sufficient to reawaken its deadened forces. Beneath its gentle influences the days lengthen, the Sun's rays strike us more vertically, and as their brilliancy increases the fields become bright with flowers, and the birds gladden the woods with their song. Gradually the sun reaches its greatest elevation, and begins to decline throughout the autumn, until winter is once more upon us.

The nearer we approach the poles, the nearer do we seem to the empire of death, and there are regions where no plant or insect can live, and which are only inhabited by whales, bears, and other animals capable of engendering heat, and preserving a sufficient store of it to protect them against the rigours of the climate.

XVIII.

I will conclude this chapter by an extract from Father Secchi's work on "The Sun," in which he summarizes the facts hitherto ascertained concerning the great orb of day.

"That igneous globe, a source of life, and cause of motion amongst the planets, was once a nebulous mass like those

* Radau's *Dernière Progrès de la Science*, p. 46.

which we now see in the depths of the sky. This mass as it grew cool gave birth to the planets and their satellites. It still preserves in its midst all the heat which must have resulted from its condensation and the collapse of its different particles, which, from the furthest limits of its domain, have, in obedience to the law of attraction, fallen towards the centre.

"This enormous mass, undergoing the phases of gradual cooling through which the planets around it have passed, may one day lose the whole of its present brilliancy, but it will yet be millions upon millions of years before this takes place. Whether something will then occur to restore its primitive powers, we cannot say, for the world's existence has had a beginning, and may, for all we know to the contrary, have an end.

"The gaseous composition of the Sun accounts for the phenomena which we notice upon its surface. The part which is exposed on the outside to radiation towards the regions beyond loses its gaseous constitution as it gets cool; it remains condensed in the shape of masses, vaporous but incandescent, in the gaseous and transparent atmosphere by which the globe is surrounded, forming a brilliant stratum which we call the *photosphere*. This stratum, like the interior of the solar body itself, is the seat of vast chemical processes and physical movements of a very complicated character. Causes as yet unknown, transporting considerable masses from the interior to the exterior, create immense gaps in the luminous stratum, and so give rise to the spots. The centre of these gaps, more obscure and more absorbent, cuts off from us the great majority of the luminous rays emanating from the central nucleus, composed as they are of a gaseous matter and quite isolated from each other.

"Above this luminous stratum spreads the atmosphere, formed of transparent vapours, which attain various degrees of altitude according to their specific weight. Hydrogen, being the least dense of all these substances, floats at a great altitude, forming columns and clouds which constitute the red prominences seen about the Sun during an eclipse. Iron and calcium are the substances most abundant in the hollow of the spots and in the rents of the photosphere.

"The Sun's atmosphere is vast, extending to a distance equal to the fourth of the solar radius; it is elliptic in shape, with a greater elevation at the equator than at the poles. In the equatorial regions, in the vicinity of the spots more especially, there is a higher degree of activity than at the poles, as is seen by the greater brilliancy and altitude of the atmospheric envelope itself.

"The spectroscope, in revealing to us the chemical composition of the Sun, has taught us that the substances of which it is formed are identical with those which constitute the terrestrial bodies. And yet we are far from possessing a knowledge as to the nature of all these substances."

The information contained in this chapter shows the progress made in the researches as to the Sun, and the rapidity with which they have been prosecuted since the discovery of spectrum analysis.

Fig. 28.—Horæ (the Seasons) from a medal of the time of Commodus.

CHAPTER V.

MERCURY.

Its phases—Truncation of its crescent—Prodigious height of its mountains—Mercury's passage across the Sun—Its volcanoes—Its distance from the Sun—Its seasons—Its density, mass, dimensions, and motions—Strange peculiarities of this planet—Is it inhabited?—Fontenelle's opinion.

I.

MERCURY is the smallest of the principal planets and the one nearest to the Sun. It is always so immersed in the rays of the latter that there is great difficulty in seeing it with the naked eye, even at the period when it is most distant from the Sun.

Yet the Greeks, struck by the occasional intensity of its light, bestowed upon it the adjective, *glittering*. Seen through the telescope, Mercury has phases like the Moon, a fact which proves its opaqueness; it is also because of this latter quality that it presents the shape of a black spot in its passage across the solar disc. Its crescent exhibits a horny truncation, discovered by Schrœter, which tends to show that this planet has mountains 53,000 feet high, or even more.

Mercury's passages across the Sun take place but rarely, because of the inclination of the orbit, occurring at intervals of three, seven, ten years, &c., and lasting less than three hours. The luminous points noticed upon its obscure disc

I

on these occasions have led to the supposition that it must contain volcanos in a state of activity.

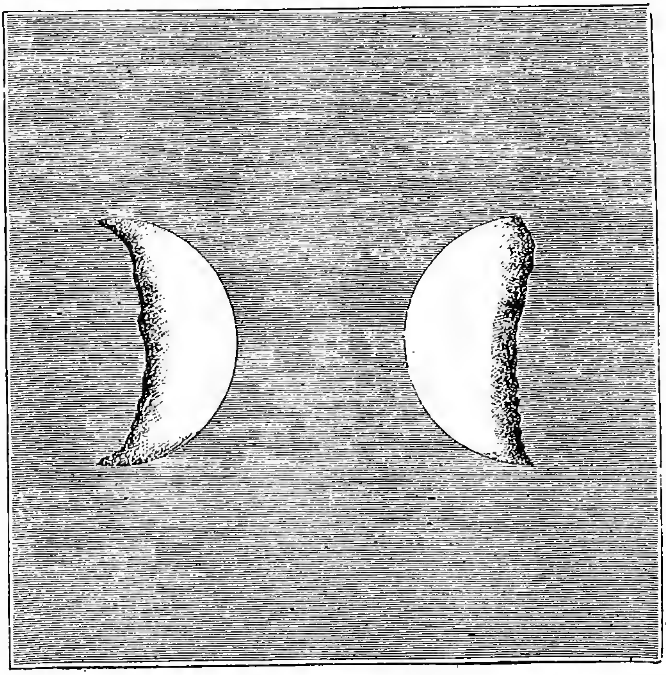


Fig. 29.—The phases of Mercury.

The mean distance of Mercury from the Sun is 35,393,000 miles, whence it follows that the Sun's diameter, seen from Mercury, appears thrice as large as it does to us, and that the temperature is seven times that of our torrid zone. This temperature, much greater than that of boiling water, is no doubt mitigated by an extensive atmosphere. Its seasons are very pronounced, for at the epoch of the solstices, for instance, the Sun attains an altitude, as compared to the polar horizons, not merely of 23° 27″, as upon the Earth, but of 70 degrees.

II.

This planet must be of a very dense character, for if the materials of which it is composed were liable to become heated like those of the Earth, they would be melted and vitrified in a very short space of time.

We know, in fact, from experiments made, that its density is one and a half times greater than the mean density of the Earth; its mass is only a twelfth that of the Earth; its volume sixteen, and its weight fifty-seven times less than that of our planet.

It traverses, in the space of 88 days an orbit of 230,208,000 miles round the Sun, or 100,000 miles an hour. It was because of this enormous velocity that the Greeks called this planet *Mercury*, the messenger of the gods.

It accomplishes in 24 hours 5 minutes and 28 seconds a rotatory movement around an axis 7 degrees inclined to the plane of the equator, so that there must be a great inequality in the days and seasons. In diameter it is about 2,962 miles, and at its least distant point, 47,229,000 miles from the Earth.

It is a peculiarity of this planet that at its perigee, that is to say the point when it is nearest to the Earth, it seems smaller than at its apogee, the point when it is farthest off, and the reason of this is that when in its perigee it is not luminous on the side towards us, while when at its apogee that portion of its disc lighted by the Sun faces the Earth.

It is somewhat strange that Copernicus, who deduced from the motion of Mercury so powerful an argument against the Ptolomæan system, lamented upon his death-bed that, in spite of all his efforts, he had never been able to see this planet. Yet its existence was known in the most remote ages, and the ancients, who did not comprehend the real system o the world, deceived by the double apparition of Mercury, sometimes after sunset, sometimes before sunrise, supposed at first that there were two distinct stars, one of which they called *Apollo*, god of the day and of light, the other, *Mercury*, god of thieves. The Indians and Egyptians, who worshipped this planet, also gave it two different names. But it was ultimately remarked that only one was visible at a time, and that the apparition of the second coincided almost exactly with the disappearance of the first; so it was discovered that they were one and the same star.

III.

If Mercury is inhabited, it must be by people constituted very differently from ourselves. Much allowance must be made for the imaginative powers of painters and poets, and with this reserve Fontenelle's description of its supposed inhabitants is worth quoting.

He says: "They are not half so far off from the Sun as we are; it seems to them nine times as large, and floods them with a light so potent that the brightest of terrestrial days would appear but dim twilight to them, if not night itself. The heat to which they are accustomed is so great that the climate even of central Africa would freeze them through. It must be taken for granted that our iron, silver, and gold, would melt in their world, and only appear as a liquid, like water. The dwellers in Mercury would be unable to comprehend that in another world these same liquids, which perhaps form their rivers, are the hardest substances with which its inhabitants are acquainted. They must be so vivacious as to be mad in our meaning of the term. I believe that they have no more memory than most negroes, that they have not the faculty of thought, that they only act by fits and starts, and that in Mercury, Bedlam is the universe."

This portrait of the supposed inhabitants of Mercury is the reverse of flattering, and there is no reason why the harmony which would be likely to subsist between their organism and climate should not admit of their intellectual and moral faculties being developed as perfectly as our own, if not more so.

CHAPTER VI.

VENUS.

Different names of this planet—Its distance from the Sun—Its translator motion—Why does it seem to vary in size?—Dull and pale light occasionally emitted by its obscure part—Visible in full daylight—Curious facts: Æneas in his voyage to Italy, and General Bonaparte at the Luxemburg—Discovery of the phases of Venus—Curious anagram—Spots observed in Venus—Its gigantic mountains—Explanation of its phases—Its passage across the Sun's disc—Its atmosphere—Why does it seem to remain longer to the east and west of the Sun than it takes time to revolve around it?—Means of ascertaining the Earth's distance from the Sun by the passage of Venus—Halley, Le Gentil, Chappe—Curious facts—Its rotatory motion around an axis—Its days and seasons—Description of this planet and its possible inhabitants.

I.

Venus is the only planet spoken of by Homer, who designates it by an epithet signifying beauty. It has also been called Juno and Isis.

The identity of the brilliant stars seen, sometimes of a morning and sometimes of an evening, was not originally known, and thus the ancients called it *Vesper*, or *the evening star*, when it set some time after the Sun; *Lucifer*, or *the morning star*, when it preceded the sunrise.

Venus was called *Sukra*, that is to say, *the brilliant*, by the Indians, and everyone is aware that it is often termed the Shepherd's star.

Micrometrical measurement shows that the apparent diameter of Venus is comprised between 9″ ·5 and 62″.

This enormous difference is due to the fact that it comes within 23,309,000 miles of our globe, and recedes to as much as 159,551,000 miles from it.

It is about 66,131,000 miles distant from the Sun, round which it accomplishes, in 224 days, 14 hours, 49 minutes, an orbit of 432,000,000 miles, travelling, therefore, at the rate of 80,000 miles an hour or 1333 a minute.

So far as we can judge, Venus has a smaller diameter, and consequently a lesser volume than the Earth, but the difference is so slight that the observations from which it has been deduced may not be altogether trustworthy. The quantity of light and heat which Venus receives from the Sun is nearly double that which reaches the Earth.

The obscure part of this planet is occasionally noticed to shed in the sky a dull, deadened kind of light, which some astronomers have attributed to the phosphorescence of the atmosphere or the solid part of this planet. This curious phenomenon may also be the result of a certain ash-coloured light, analogous to that of the Moon, and which would be caused by the light reflected from the Earth or Mercury to Venus. Perhaps, too, the atmosphere of the planet may be in certain cases the seat of lights analogous to those which, on the Earth, constitute Auroræ Boreales.

II.

Venus is sometimes so resplendent as to be visible at mid-day to the naked eye, and the uninformed masses have linked its appearance with important contemporary events, just as has been the case with comets.

The ancients remarked that at night when there was no moon, the light of Venus often projected shadows. Æneas, as we are told by Varro, during his voyage from Troy to Italy saw this planet the whole time, even while the Sun was above the horizon. The same author, in one of his works that is now not extant, is reported by St. Augustine to have said that Venus had, at an epoch long before his own time, undergone a change of colour and intensity.

General Bonaparte, on his way to a fête at the Luxemburg Palace, was struck by the attitude of a crowd in the Rue de Tournon, which had assembled to gaze at a star, which was visible, though it was then mid-day. This planet, which was Venus, they took to be the guiding star of the celebrated general, who had just returned from his Italian campaign. It is a singular fact that it was not until some time after its discovery that Galileo thought of observing whether or not Venus had phases, a point which he settled in the affirmative on the 10th of September, 1610.

In order to follow up and verify this discovery without running the risk of having it appropriated by others, he concealed it under the following anagram:—

Hæc immatura à me jam frustra leguntur. o, y.

Changing the order of letters, Galileo read the line thus:—

Cythiæ figuras emulatur mater amorum.

Father Castelli asked Galileo, in November, 1610, whether Venus and Mars did not both present phases, to which the astronomer of Florence, who at first gave an equivocal answer, replied a month later by announcing the discovery of phases in Venus.

III.

The dark spots noticeable in Venus extend over a large part of its diameter; their extremities are not very sharply defined.

Branchini noticed, in 1726, seven spots in the centre of Venus, which he termed seas communicating with one another by means of straits, and exhibiting eight distinct promontories. He drew illustrations of them, and named them after his patron, the King of Portugal, and the most distinguished navigators. In 1700, La Hire, observing Venus by daylight near its lower conjunction, with a magnifying glass of 90 degrees, noticed upon the inside of the crescent an unevenness of surface which could only be due to the presence of mountains higher than those of the moon.

Schrœter, directing his attention to that part of the crescent nearest its horns, noticed that they were occasionally truncated.

Upon the 28th of December, 1789, January 30th, 1790, and February 27th, 1793, he remarked near the southern horn a luminous point entirely isolated, that is to say, separated by an obscure patch from the rest of the crescent.

If the planet were free from rugosities and perfectly smooth, the crescent would invariably terminate in two extremities quite parallel and very pointed; but if Venus is covered with mountains, their interception of the luminous rays proceeding from the sun will at times prevent one or even both of these horns from assuming their regular shape, and the crescent will not therefore be completely symmetrical.

As a matter of fact, Venus is not a smooth body; it has mountains upon its surface, and these mountains far exceed in height those of the earth. From measurements taken it seems that they are 145,200 feet high, or five times the altitude of the highest mountains upon the earth.

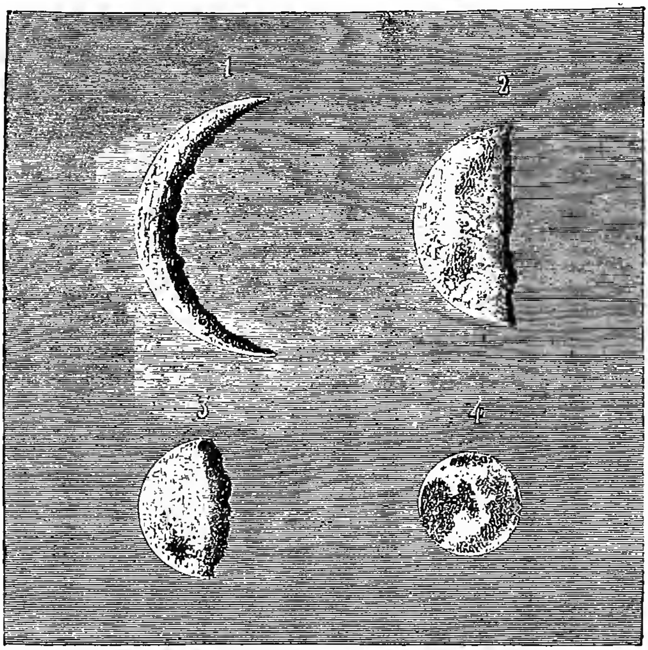


Fig. 30.—The phases of Venus.

When Venus sinks of a morning into the Sun's rays, or when, of an evening, it emerges from them, its diameter is very small, and its disc nearly round.

This diameter is much larger, and the planet seems very concave, like the moon under similar circumstances, when it disappears of an evening, or emerges of a morning from out of the twilight-dawn.

The concavity of its crescent faces to the east of an evening, and to the west of a morning. It is half full at the

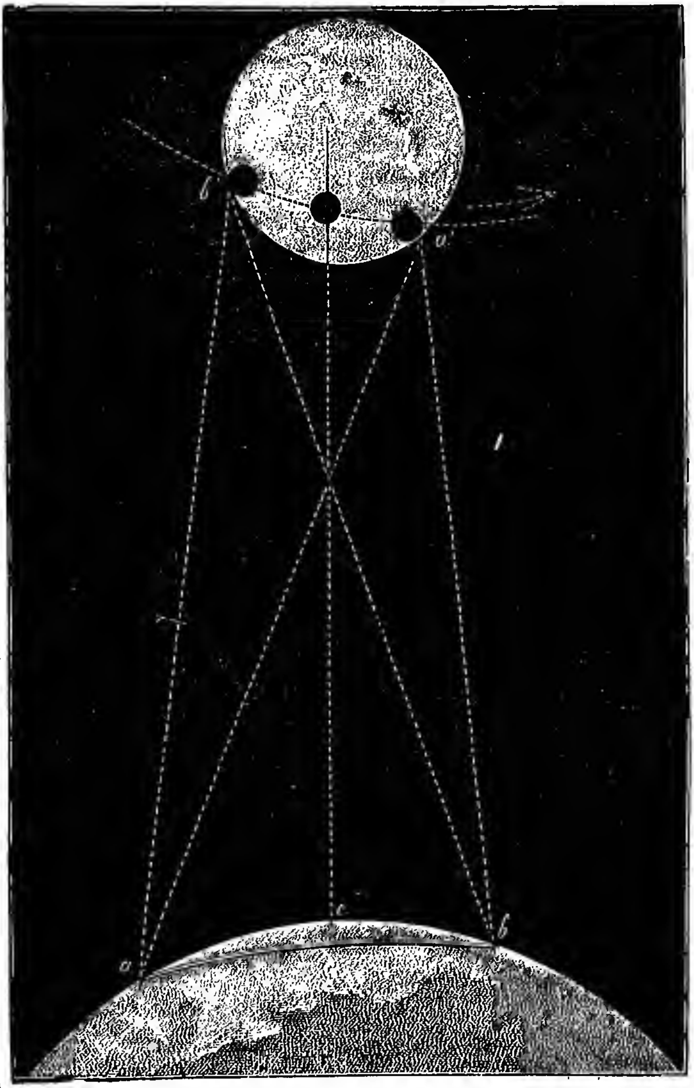


Fig. 31.—The passage of Venus across the Sun.

periods intermediate between those mentioned, phenomena which admit of a very simple explanation, if we suppose that Venus circulates in a closed curve, with the Sun inside, that it is not luminous of itself, and that the greater part of the light which we see there is borrowed from the Sun.

As Venus is situated beyond the Sun in the same latitude, and crosses the meridian at noon, it is then said to be in *upper conjunction;* the *lower conjunction* also occurs at noon, at the epoch when Venus and the Sun have the same latitude, the former occupying a position between the latter and the earth.

Venus passes across the Sun's disc in the direction of left to right, like a black spot with an apparent diameter of 59 seconds. Its passages are of very rare occurrence; the first that was made the subject of observation took place in November, 1631; the next on June 5th, 1761, and the third on June 3rd, 1769. After occurring at an interval of eight years, there was a lapse of one hundred and thirteen and a half years before the next, which takes place upon the 8th of December, 1874, and will be followed as before, by another passage in 1882. This is the order of their periodicity, the cause of which is the inclination of Venus to the ecliptic. It is worthy of notice that its passages across the solar disc serve to ascertain the Sun's parallax, and its distance from the earth.

Fig. 81 represents the passage of Venus across the Sun, observed from three different points, A, B, C. At the moment of its passage it is about two and a half times nearer to us than the Sun is. Its parallax is therefore very considerable. Let us suppose two observers, A and B, to be placed at the extremities of a terrestrial diameter, and making allowance for the rotatory motion of the earth, each of them will be able to measure the chord described by the planet, either directly, or by estimating the time occupied in its passage, for the angular motion being well known, the time taken will show what space has been traversed. The length of two chords starting from *a b* being known, their distance *a b* will easily be ascertained, and, by means of two triangles with bases A *b* B and A *a* B, it will be found that the distance of the chords is equal to five times the radius of the earth. Therefore the angle at which the distance *a b* is seen from the earth is five times greater than the angle at which the terrestrial radius would be seen from the Sun, or five times the solar parallax. Thus, by taking the fifth of the distance, *a b*, we obtain the parallax of Venus.

IV.

Halley, the great English astronomer, was the first to indicate the passage of Venus as a means of obtaining the parallax of the Sun or its distance from the earth. Though Halley must have known that his method could not be employed in his own lifetime, he nevertheless strongly recommended it, thinking more of the service he could render humanity than of lamenting that the brevity of human life would prevent him from reaping the benefits of his discovery."*

The importance of the passage of Venus across the Sun from a scientific point of view has been the cause of many perilous expeditions. As the author just quoted remarks: Imitating the heroic devotion to duty displayed by Halley, astronomers scoured the whole globe to observe the passages of this planet. One of them, Le Gentil de la Galai-

* *Treatise on Astronomy,* y Petit, ex-director of the Toulouse Observatory vol. ii. p. 137.

sière, starting from India in March, 1760, and hindered by the war then going on between the French and English, had the patience to await at Pondicherry for eight long years the passage of 1769, risking the loss of his post at the Paris Académie des Sciences, where, in default of news from him, his vacant place was filled up. Thus he risked his patrimony, and failed after all in the object of his research, for after obtaining but a cursory glimpse of the passage of 1761, from the deck of a ship, he was altogether prevented from observing that of 1769, owing to the cloudy state of the sky."

The Abbé Chappe d'Auteroche, after making the journey to Siberia, in order to observe the passage of Venus in 1761, died of yellow fever in California, on the 1st of August, 1769, at the age of 41, and this because he would insist upon remaining an extra fortnight in the tainted district, in order to observe an eclipse of the moon, in addition to the passage of Venus.

Many other men of science also visited the most distant parts of the continent, in order to take observations, and their labour was not unrewarded, enabling them, as it did, to determine with precision the unity of the celestial longitudes, and the actual distance from the earth to the Sun. The accuracy of their measurements will, beyond doubt, be confirmed on the occasion of the coming passages this year (1874), and in 1882.

M. Faye, in his final discourse as President of the French Academy of Sciences, stated that the committee appointed for observing this phenomenon, though much hampered by the painful events of the last few years, had taken every measure for obtaining a successful result.

V.

It has been calculated that Venus has an atmosphere very similar to that of the earth as regards its extent and diffractive force, the estimate being based on the shadow which appears on the Sun's surface a few seconds before the dark body of Venus reaches the solar edges on the occasion of its passage.

This observation is further confirmed by the law as to the gradual variation of the light as it passes from the side which is illuminated to that which is not. During 190 days alternatively, it appears as a morning and evening star, and though it may seem surprising that it should appear to remain longer to the east and west of the Sun than it takes time to accomplish its period around that luminary, this difference is easy of comprehension when we remember that the earth itself revolves round the Sun, and that it follows Venus in its course, but at a lower rate of velocity.

Dominico Cassini discovered the fact of its rotatory motion around an axis forming a sharp angle with the ecliptic, which must cause, as in Mercury, a great inequality in the days and seasons. The duration of this rotatory motion has been fixed at 23 hours, 21 minutes, 7 seconds.

I will conclude this chapter with a passage from the author of *Harmonies de la Nature*, descriptive of this planet and its possible inhabitants:

"Venus must be studded with islands, each of them containing mountain peaks five or six times higher than that of Teneriffe, their sides bright with verdure and flowers.

"Its seas must present the most attractive spectacle. Imagine the Swiss glaciers, with their torrents, their lakes, their meadows and their pinewoods in the midst of a southern sea; add to their sides the Loire hills, crowned with vines and fruit-trees, and to their bases the tropical produce of the Moluccas and the bright-plumed birds of Java. Imagine their shores overshadowed with cocoa-trees, studded with oyster-beds, madrepores and corals growing, amidst perpetual summer, to the height of large trees in the bosom of the ocean, rising above the water at the ebbing of the tide, which lasts for 25 days, and harmonizing their scarlet and purple hues with the verdure of the palm-trees.* And imagine, finally, currents of transparent water which reflect all these beautiful spectacles, ebbing and flowing from isle to isle with a flood of twelve days and a reflux of twelve nights, and even with all this you will have but a very faint idea of the landscape in Venus. As the Sun at the solstice rises more than 71 degrees above its equator, the pole which illuminates it must possess a temperature much milder than our spring. Though the long nights in this planet have no moons to light them, Mercury, by reason of its brilliancy and close vicinity, and the earth, by reason of its size, must be more than equal to two moons.

"Its inhabitants, about the same size as ourselves, since they dwell in a planet of the same diameter, but in a more favoured celestial zone, must devote all their time to love. Some, feeding their flocks upon the hill sides, lead the life of a shepherd; others, upon the shores of their fruitful islands, join in dancing and feasting, and pass the time in singing or swimming for prizes, like the inhabitants of Tahiti."

It is no exaggeration to say that in this case the imagination probably falls below the reality.

* For an accurate description of these marvels, see *Histoire des Pierres précieuses*, p. 139. (Firmin-Didot & Co.)

CHAPTER VII.

THE EARTH.

Its origin—Its transformations—Summary of what is known concerning the globe's crust, by Élie de Beaumont—Cooling of the globe—Temperature of the Celestial regions—Shape and dimensions of the Earth—Its chief divisions: continents and seas—Proofs that the Earth is almost spherical—Flattened shape at the Poles—Attraction—Its various kinds—Exact date of the establishment of the law of attraction—Scientific hypothesis as to this law—History of M. Bertrand's measurement of the Earth—Various motions of the Earth—Kepler, his genius and discoveries—The seasons—Variations of day and night—History of the Earth's translatory motion round the Sun, by Arago.

I.

The Earth, our common mother, to borrow a term from the ancients, has naturally been the subject of study amongst men of science from the earliest ages.

The observations of geologists have shown that our planet has only reached its present condition after undergoing, for an incalculable period, numerous revolutions, traces of which are everywhere to be found.

Everything tends to prove that the Earth was in the first place incandescent, and has since gradually become cooler; the existence of an internal focus is shown by the increase of heat that takes place in the various strata of the globe in proportion to their greater depth, and this increase is about one degree centigrade for every thirty-two yards in depth.

All the luminaries in our planetary system appear to have a common origin. In conformity with these ideas, it seems rational to refer the chaos spoken of in the Bible to the existence of a vast nebula, which, turning upon its own axis, and very much flattened by the effect of the centrifugal forces caused by its rotation, would, during the successive phases of its cooling, have cast off several of its strata, the accumulation of which in globules, corresponding with the separation of darkness from light, would be the origin of the earth, the other planets, and the satellites. This view, which is not the least inconsistent with the strictest tenets of religion, is held by many of the most distinguished astronomers and geologists, Father Secchi, director of the Roman observatory, among them. (See pp. 37 and 38.)

This theory is confirmed by all the known phenomena; the rounded surface of the globe, the flattening at the poles, central heat, the parallelism of the indentations which, as M. Élie de Beaumont has proved, have been formed at each cataclysm of the globe's surface, the analogy with what takes place in the heavens when stars are in process of formation, &c., &c.

Thus the earth must have passed in succession from the gaseous to the liquid and solid state; and even now everything tends to show that, under the relatively thin crust of 49,500 yards, which we inhabit and cultivate, the substances composing it are, if not in a liquid, at all events in a pulpy state.

II.

Élie de Beaumont, summing up the knowledge which we possess concerning the earth's crust, points out that if the terrestrial rind results from the superficial cooling of the substances in a state of fusion which originally constituted the exterior envelope of the globe, the action attributable to the attractive forces upon those parts which are not yet cool, cannot form ground for surprise. The data generally accepted as correct forbid the supposition that the crust is more than 49,500 yards thick, or in other terms, $\frac{1}{140}$ of the terrestrial radius. Such a shell is, by comparison, thinner than that of an egg. Split in all directions, like the rocks which we see upon the surface of the globe, a vault of such slight thickness could not hold up without some supports, and must give in such a way as to bear upon the incandescent substances beneath it.

These substances are consequently exposed to great pressure, which must very much reduce the mobility of their molecules, and give them almost the properties of a solid body. The refrigerated crust becomes, so to speak, embodied with this incandescent substance, which, though not actually in fusion because of the pressure upon it, is at fusion temperature. Hence it results that the whole mass of the globe undergoes the action of the attractive forces as if it were a solid body. It must possess, however, a certain degree of malleability, as is denoted by the remarkable affinity which M. Alexis Perrey has shown to exist between the frequency of earthquakes and the Moon's phases.

The refrigerated crust of our globe, getting gradually thicker as the cooling process continues, would eventually acquire sufficient rigidity to maintain itself without extraneous support. The less refrigerated substances beneath it would then be released from the pressure to which they are now subjected, and an annular void might even be established between the solid crust and the substances still sufficiently inflamed to remain liquid, close to their surface at least, in the absence of any pressure. But we must hope that the cooling of the globe has not yet reached this point, which would probably cause a catastrophe of unexampled magnitude. It would be due to the introduction of the sea into the empty space between the lower and still incandescent surface of the solidified crust and the upper surface of the substances still in a state of fusion.

The final phase of the relative refrigeration of the whole mass and surface of the globe, as given by Plana, will not be complete until 156 milliards of years, counting from the time when the cooling process began.* The recent researches of M. Poisson lead to the conclusion that all the geological phenomena which have hitherto occurred may be comprised in a period of a hundred million years, or even less.†

III.

Those parts of the mineral crust of the globe which geologists call *sedimentary rocks* were not formed all at once.

Science furnishes us with the following details upon this subject. At one time the regions now situated in the centre of the continent were covered on more than one occasion with water, which deposited there thin horizontal strata of various kinds of rock. These rocks, placed one upon another, like the stones in a wall, must not be taken to be all alike, and, in fact, the difference between them must strike the least practised eye. The crystalline granitic rocks, upon which the sea made its first deposits, have

* The printed text in the Turin Academy gives ninety-six milliards of years, but the correct calculation is that given above.

† *Académie des Sciences,* first half of 1871.

never exhibited any vestige of a living thing. These vestiges are only to be found in the sedimentary strata.

Vegetable débris is the only thing to be met with in the oldest strata deposited by the waters, and even they belong to plants of the simplest composition, such as ferns, rushes, and lycopods.

Vegetation becomes more and more composite in the upper strata, and in the most recent it may be compared to the vegetation of the present day, with, however, the significant restriction that certain vegetables which only exist in the south, such as the large palm-trees, are to be found in a fossil state at all latitudes, even in the midst of the icy regions of Siberia.

In the primitive world, therefore, these hyperborean countries had a temperature at least as elevated as that of the parallels where the palm-trees now flourish; Tobolsk, for instance, must have had as warm a climate as that of Alicante or Algiers in the present day. A careful examination of vegetable substances confirms this view. Thus, though shave-grass and rushes, ferns, and lycopods are to be met with in the present day in Europe as well as in the equinoctial regions, they never attain the same dimensions in the former as in the latter countries. To compare the dimensions of the same plants is equivalent to a comparison of the temperature of the regions in which they grow. But if we compare the fossil plants of our coal-producing regions with the plants which grow in the richest parts of South America, it will be seen that the former are far and away the largest.

The *fossil flora* of France, England, Germany, and Scandinavia, contain ferns fifteen yards high, the stems of which are a yard in diameter.

The lycopods, which, in cold or temperate countries are creeping plants, hardly rising four inches above the soil, and which even at the equator do not attain a height of more than three feet, grew to a height of eighty feet in the primitive world, even in Europe. These enormous dimensions are an additional proof of the elevated temperature which reigned there previous to the last invasion of the ocean.

By studying the fossil animals we arrive at similar results. Amongst the bones contained in the soil nearest to the present surface of the globe, are the remains of hippopotami, elephants, and rhinoceros. These remains of animals indigenous to a hot country, are to be found under all latitudes, even at Melville Isle, where the temperature now falls to fifty degrees centigrade below zero. In Siberia they are so abundant as to have been the object of a trade speculation; and upon the cliffs bordering upon the frozen strait are to be found not merely skeletons, but whole elephants with their skin and flesh in a state of perfect preservation.

Thus the polar regions have, in the course of time, undergone an enormous process of refrigeration, caused not by any change of the Sun, but by the dissipation of an original heat of their own, or with which the Earth was once impregnated. Even before the discovery of the elephants in Siberia, science had conceived the idea that the globe must have had a heat of its own, in proof of which Mairan and Buffon instanced the high temperature of certain deep mines, Giromagny amongst others.

Fourier was one of the first to examine this question, and he pointed out the great influence of *the temperature of the celestial regions*, amidst which the Earth describes its immense orbit round the Sun.

Meteorologists had supposed, when they saw even at the equator certain mountains covered with perpetual snow, and when they observed the rapid decrease in temperature of the atmospheric strata during a balloon ascent, that the regions beyond the atmosphere must be enveloped in hundreds and thousands of degrees of cold. But Fourier's minute investigations taught us that stellar radiation maintains the regions traversed by the planets of our system at from fifty to sixty degrees centigrade *below zero*. The temperature of the earth increases by a degree at every thirty or forty yards depth below the surface, according to the nature of the soil; the temperature of the air diminishes in the same proportion at every 160 or 200 yards of altitude.

IV.

The shape of the earth is that of a spheroid, flattened at the poles, and bulged out at the equator, the flattening being about $\frac{1}{300}$ of the radius.

The inhabitants of the Earth, who are diametrically opposite to each other in respect to the regions which they inhabit, are called antipodes, as also are the places in which they live. The point of the sky situated directly above their heads is called their *zenith*, and the name of *nadir* has been given to the opposite point.

The Earth's circumference is about 24,000 miles, and the highest mountains do not reach five miles, an altitude which, being not quite the five-thousandth part of the circumference, is very slight in comparison to the extent of the Earth, and makes no more alteration in its shape than an eminence of ·03937 of an inch would upon a globe 17 feet in circumference.

A few grains of sand upon a ball, or the unevenness upon the contour of an orange do not prevent those bodies from being round, and such is exactly the case with the mountains upon the terrestrial surface.

The Earth's shape is precisely that which would be presented by a fluid mass, endowed with a rotatory motion around a fixed axis. The air which envelops the Earth upon every side, like the solid or liquid parts which obey the laws of gravity, must have the same shape.

In proportion as we recede from a body, the details become effaced, and the main features more and more apparent. Thus the Earth, as seen from a great distance, the Moon for instance, would present the aspect of a spherical globe, round and luminous like the Moon itself.

I will now proceed to mention the chief arguments advanced to prove that it is nearly spherical or round. To convince us of the fact, let it be imagined that the Earth was a plane or quite flat. In that case, as soon as the Sun appeared upon the horizon, its light would be immediately diffused over the whole terrestrial surface alike. This, as we know, does not take place, and proves therefore that the Earth is more or less convex. A vessel sailing away from us would seem to decrease only in size if the Earth was level, but, as a matter of fact, the hull first disappears, then the sails, and, last of all, the masts; and in coming towards us a vessel seems gradually to rise out of the water. This can only be accounted for by convexity of the Earth's surface; and as it occurs everywhere alike, the Earth must necessarily be spherical.

Magellan, the first traveller who made the voyage round the world, recognised this fact. Starting from Spain westward, one of his vessels returned to Europe in an opposite direction, that is to say, as if it was coming from the East.

The change in the aspect of the sky as one recedes from

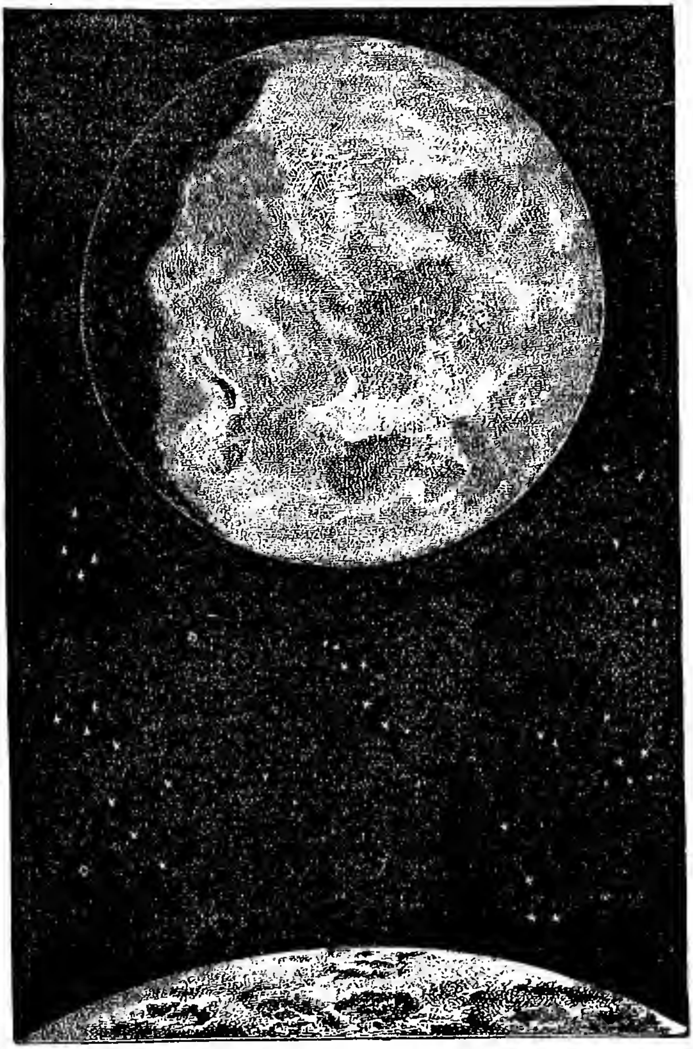


Fig. 32.—The Earth, as seen from the Moon

the spot which formed the starting-point is a further proof of the Earth's convexity. No matter in what direction we travel, fresh stars become visible; those towards which we advance seem to rise, and those from which we recede to sink in the sky and at last become invisible beneath the horizon.

The curvature of the Earth alone produces these phenomena. The spherically-shaped shadow which the Earth projects against the Moon when there is an eclipse of the latter, that is to say when the Earth comes between the Sun and the Moon, and intercepts the rays of the former, proves to demonstration the sphericity of the Earth, for it is only a sphere which, no matter how it is placed, can produce a round shadow.

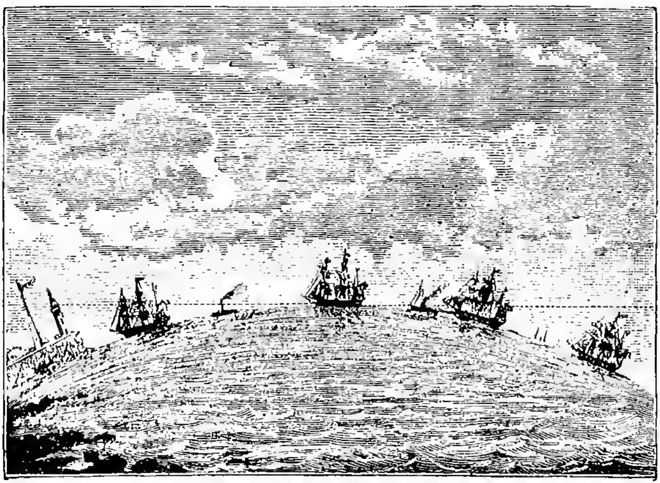


Fig. 33.—Phenomena produced by the sphericity of the Earth.

The flattening of the poles is also clearly proved by the attractive influence of the Earth upon the Moon.

M. Delaunay, referring to this subject, says:—"As the

Earth is a globe, slightly flattened towards the poles, and bulging out at the equator, its influence upon the Moon is not quite the same as it would be were it altogether spherical in shape. There must consequently exist in the Moon's motion some indications of this flattening of the terrestrial globe, and if it is possible by observation to determine the proportions of the effect caused by this depression of the Earth, it follows that the extent of the depression itself may be deduced therefrom. This Laplace demonstrated, and his calculation is almost identical with that which has been arrived at by various measurements of the terrestrial surface. We may even coincide with that celebrated geometer in his opinion that a study of the Moon's motion is for this purpose far preferable to geodesical measurements, because it is the depression of the globe as a whole, and apart from any small local irregularities, which is manifested in the Moon's motion; whereas the geodesical measurements taken at the various points of the Earth's surface are more or less affected by these local irregularities." *

V.

If the earth is globular, how comes it that houses, men, animals, and all the objects upon its surface keep their balance? Why do not the waters of the seas and rivers run out of their beds?

The answer is simple enough. Everybody must be acquainted with the effect of a loadstone. Place some iron-filings in close proximity to it, they would be attracted by it, and only those upon which the loadstone failed to exer-

* Delaunay's *Annuaire du Bureau des longitudes*, 1868, p. 462.

cise sufficient attractive force would fall off. The Earth possesses force of a similar kind, by means of which it attracts to its centre all the bodies upon its surface, and when one of them falls it is always towards the Earth's centre.

The fruit from its stem, the stone from the hand which held it, fall to the surface of the Earth, impelled by that hidden force which has been termed *attraction.*

This force is resident in all the bodies of nature. It exercises its influence upon the largest masses as well as upon the most minute particles of matter. This it is which gives harmony to the universe, and explains the formation of bodies of all kinds.

It makes itself felt throughout all matter just as if that matter had no existence, so that to discern the effect produced by a spherical stratum upon a point beyond, it is necessary to add together the influence of all its elements, without making any distinction between those which act directly or indirectly.

Attraction takes different names according to the kind ot action which it exercises.

When it merely unites the different molecules which constitute a body, it is *molecular attraction.* When it is the invisible bond of union between the diverse elements which constitute our globe, or the force which precipitates to its surface the bodies which had been separated from it, it is *gravity.* And, lastly, when it presides over the preservation of the order reigning in the universe, by retention of the celestial bodies in the limits of their accustomed course, it takes the name of *celestial gravity,* and furnishes the principal laws of astronomy.

VI.

The motions of the celestial bodies, since the time when they were first observed, accord to demonstrate the truth of two principles discovered by Newton, which may be stated as follows:—

1st. *Bodies exercise attraction in direct ratio to their mass.*—For instance, a body weighing a pound, attracts like a pound; if it weighs two,.its attractive force is doubled; if three, it is trebled, and so on.

2nd. *Bodies exercise attraction in inverse ratio to the square of their distances.*—The square of a number is the product of that number multiplied by itself. Thus, the square of 2 is 4; of 3, 9; of 4, 16, and so on. Consequently, at double the distance, the attractive force is four times less; at treble the distance, nine times less, &c., &c.

Let us suppose the mass of one body to be four times that of another, it will attract with four times the force, and if the two bodies are both movable, that of which the mass is four times greater than the other will only be displaced one-fourth as much. Moreover, if the distance separating the two bodies is four, five, ten times greater, they will attract sixteen, twenty-five, a hundred times less.

A body which upon the earth weighed 3,600 pounds, would only weigh one pound if it was as far off as the Moon; that is to say, it would be 3,600 times less attracted by the Earth, and might, to use Euler's expression, be held up with one finger.

The fall of bodies to the ground follows the same laws. If, for instance, a stone is launched into the air, there will be a free exchange of attraction between it and the Earth, but as attraction is in direct ratio to the masses, the Earth, having a mass infinitely larger than the stone, will not be displaced to any appreciable extent.

Gravity imparts equal degrees of speed to all bodies falling from the same height, whatever may be their character, shape, or volume. This is easily proved by placing within a long glass tube bodies of various kinds, such as lead, cork, paper, and feathers, and then extracting the air from it with a pneumatic machine. When the void has been created, the tube is placed in a vertical position, and turned upside down, when the lead, cork, paper, &c., descend with the same velocity as if they were one undivided body. If the air is readmitted into the tube, the lighter bodies will again be distanced by the heavier substances, and the differences between them will go on increasing until the air inside the tube has acquired the density of that outside.

M. Babinet, whose recent death deprived the French Institute of a very valued member, wrote as follows concerning the discovery of the law of attraction:—

"In 1666, Newton, while living in retirement in the country, gave his attention for the first time to the system of the world. Several authors had already asserted that the law of attraction was in inverse ratio to the square of the distance. Newton, in essaying the truth of this law by comparing the fall of the Moon to the fall of weighty bodies, found it to be false, and did not, therefore, prosecute the inquiry any further. Four years later, he ascertained, by means of Picard's French measurement, that this important law was perfectly correct, and from that time, *but not before*, the law of attraction was an established fact. It is well known that when Newton received the results of Picard's measurements, he was so excited that he was obliged to ask one of his friends to complete the simple calculation which verified this important law, which, accurately speaking, dates from 1670."

VII.

M. Emanuel Keller has furnished the Académie des Sciences with a paper upon the *cause of gravity and the effects attributable to universal attraction*, of which the following interesting paragraph is an extract:—

"Newton, during the last fifty years (1675—1726) of his life was always studying the cause of gravity, at one time examining its motions, at another the difference in the density of the ether, and, though he failed to assign them their precise places, he was anxious that nobody should suspect him of having ever given serious belief to the hypothesis of attraction without contact. This is evident in several of his works, notably in the second edition of the *Optics*, and in his letter to Bentley, wherein he says: 'It is absurd to suppose that inert nature can exercise any action save by contact; and the idea that gravity should be an innate quality, inherent, essential to bodies and permitting them to react upon each other from a distance, and with a void between them, without any intermediary for transmitting this force, seems to me so ridiculous that it is not worth while to waste time in discussing it.'"

M. Lamé, in his *Leçons sur l'Élasticité*, propounds the same idea:—

"The existence of the ethereal fluid is proved beyond question by the propagation of light in the planetary regions, as also by the simple yet convincing phenomena of diffraction in the theory of undulations; and the laws of double refraction prove not less surely that ether exists in all the diaphanous regions. Thus ponderable nature is not alone in the universe; its particles swim, so to speak, in the midst of a fluid. If this fluid is not the only cause of all the facts that have been observed, it must at all events modify and multiply them, and complicate their laws. Thus we cannot obtain a rational and complete explanation of the phenomena of physical nature without taking into account this agent, always and necessarily present. And there can be no doubt that through it will be discovered the veritable origin of the effects attributed to calorics, electricity, magnetism, *universal attraction*, cohesion, and chemical affinities; for all these mysterious and incomprehensible creations are, after all, mere co-ordinating hypotheses, useful, no doubt, in our present ignorant condition, but which will be displaced by the ultimate discoveries of true science."

From these statements, carrying great authority with them, we may infer that gravity is to be explained by the intervention of ether, and it is only as to the form of this intervention that there can be any doubt. M. Keller holds that every weighty article is subject, in the midst of the ether, like a vessel upon the water, to two orders of forces, the one circular, the other perpendicular, and that the latter produces the motion called gravity.

VIII.

M. Bertrand, of the Institute, lecturing upon this subject at the Sorbonne, says that the Earth has long been known to be spherical in shape, and the ancients endeavoured even to ascertain its dimensions. Aristotle estimated the circumference of our globe at 40,000 stadia (a *stadion* is 606 feet 9 inches), which was much below the mark, just as the calculation of Archimedes was far too excessive. Louis XIV., in founding the Academy of Sciences, enjoined it to ascertain the true dimensions of the Earth; and Picard, by taking a direct measurement of several degrees, enabled that body to arrive at a fairly accurate conclusion.

In none of these experiments did anything occur to raise a doubt as to the perfect sphericity of the Earth. But M. Richet, the astronomer, on his arrival at Cayenne to take some observations, was astonished to find that the pendulum of his clock, which marked the seconds very accurately in France, did not oscillate so rapidly in Guiana, and he was obliged to shorten it a full length in order to procure a swing lasting exactly a second.

Upon his return to France, the inverse phenomenon occurred, and he was compelled to lengthen it by just as much as he had shortened it in Guiana. As a pendulum is caused to oscillate by the force of gravity, or, in other terms, of terrestrial attraction, it seemed as if there must be a diminution of gravity in the equatorial region.

Fontenelle said that this was an exception which theory had not foreseen, but he was mistaken in this respect, as Huyghens and Newton had indicated, and even calculated the degree of gravity in the region of the equator. We know, in fact, that when a body revolves around a centre describing a circumference, there is a development of what is called *centrifugal force*, which is constantly tending to make it deviate according to the tangent from the circumference which it is describing. The greater the extent of the circumference described, the greater is the centrifugal force.

We know, too, that the Earth has a rotatory motion upon itself which takes place around an axis passing through the poles. All bodies, therefore, placed upon the surface of our globe describe each day a circumference, which is *zero* at the pole itself, but which increases to the equator. This rotatory movement engenders a centrifugal force, which causes a corresponding diminution of gravity, and the decrease at the equator itself is $\frac{1}{289}$ of the weight of the body.

Here we have one cause of the diminution in the rapidity of the pendular swing, but it only accounts for two-thirds of the effects remarked. We must therefore look for a second cause in explanation of the third effect, and this also has been indicated by Newton and Huyghens, viz., the flattening of the Earth at the poles, on account of which an object placed at the poles is nearer to the centre of the Earth, and consequently more attracted than a body placed at the equator.

Newton's theory was universally accepted, and one necessary deduction from it was that the degrees must be longer at the poles than at the equator. But Cassini, in his measurements of the degrees from Paris to the Pyrenees, when executing a map of France, found that the degrees increased in length as he moved southward. This fact he communicated to the Academy of Sciences, which hesitated to accept it as correct, because it was opposed to Newton's theory; but Cassini, continuing his measurements northward, from Paris to Dunkirk, arrived at the same result.

The conclusion, of course, was that the Earth instead of being depressed at the poles, as Newton asserted, must be, on the contrary, elongated; and the subject created a great division of sentiment, one party advocating the accuracy of

Cassini's calculations, the other upholding Newton. In order to settle the question, the Academy decided, in 1736, to entrust the task of measuring the degrees to two committees, one of which, presided over by Clairault and Maupertuis, proceeded to the polar regions; the other, with La Condamine at its head, to the inter-tropical regions.

It is scarcely necessary to say that the arc of a meridian extending to any considerable distance cannot be measured with a chain like a plot of land, for, to say nothing of the unevenness of the ground which must be taken into account, the imperfect character of our measuring instruments would cause the grossest errors to be made. The mode of procedure is as follows: a base not less than five miles long is selected, choice being made of a perfectly flat surface, and this base is measured with the most perfect instruments obtainable. From each extremity of this base a common point of view is fixed upon, so that the two visual rays which reach this landmark form, with the base itself, a triangle of which one side and two angles are known. A simple sum in trigonometry will ascertain the three remaining elements of this triangle, that is to say, the other two sides and the third angle.

The proportions of this first triangle fixed, a second is constructed in a similar way upon one side of the first; then a third upon the second, a fourth upon the third, and so on. In this way there is formed a body of triangles, so placed as to be pierced by the meridian line, which it is sought to measure, and permitting of an exact calculation being made as to the length of this line between two given points. The committee, after selecting a base, went on to draw the triangles. In the course of geodesical operations in France, a church tower was always selected as a landmark; but this was impossible in Lapland, and there was great difficulty in obtaining a point of view, for the country was covered with forests. It was found necessary to cut down trees upon the hill-tops, and construct scaffoldings to act as landmarks. The Sun, too, was very scorching, and the mosquitoes proved very troublesome. Finally, however, the triangles were completed, and the committee returned to their starting-point to measure the base. But in the meanwhile winter had come on, and they suffered as much from the cold as they had previously done from the heat. Still, by making the best use of the twelve minutes clear light, which was all they could count upon at this season, and assisted by the Aurora Borealis, always so frequent during the long polar nights, they were enabled to measure the base in seven days, and ascertained it to be 14,800 yards. They divided themselves into two parties to take this measurement, one party measuring from right to left, and the other from left to right, so that there might be no mistake. Their respective measurements coincided exactly, and the conclusion of their long labour was that the degree in Lapland, close to the pole, was 1012 yards longer than the French degree as measured by Cassini.

The committee despatched to the regions of the equator, arrived at a result which coincided very accurately with the above, for they found that the degree was about a thousand yards shorter than in France. Thus, it was established that the degree increases in length from the equator to the pole.*

* Bertrand's *Clairault et la Mesure de la Terre.*

IX.

Various procedures, yielding different results, have been adopted to calculate the mean density of the Earth, and, as a natural consequence, its weight.

Calculations based upon the attraction of mountains, upon the pendulum, upon the torsion-balance, and the subterranean pendulum, have all been employed. M. Faye, in a communication to the Académie des Sciences (April 11th, 1873), mentions all the estimates hitherto formed, which it may be interesting to reproduce.

Carlini and Plana, by experiments with the pendulum on Mont Cenis, were led to put the Earth's density at 4·39; Maskelyne, Hutton, and Playfair, by the deviation from the vertical on Mount Schehallion, estimated it at 4·71; Sir H. James, by the deviation from the vertical on Arthur's seat (Edinburgh), at 5·32; Reich, by Mitchell's torsion-balance, 5·44; Cavendish and Bailly, by the same method, at 5·45 and 5·66; Airy, by the pendulum and a mine-shaft, 400 metres deep, at 6·57.

MM. Cornu and Baille have published the results of recent experiments, whence they gather that the mean density of the Earth is represented by 5·56; and, by a careful interpretation of Bailly's observations, they re-establish a complete concordance between all the results obtained up to the present time.

The Earth, being at a mean distance of 91,430,000 miles from the Sun, must traverse in one year an orbit of more than 595,850,000 miles; that is 632,000 miles a day, or 68,000 miles an hour. Such a rate of speed, though a hundred times greater than that of a cannon ball, is only half that of Mercury in its orbit.

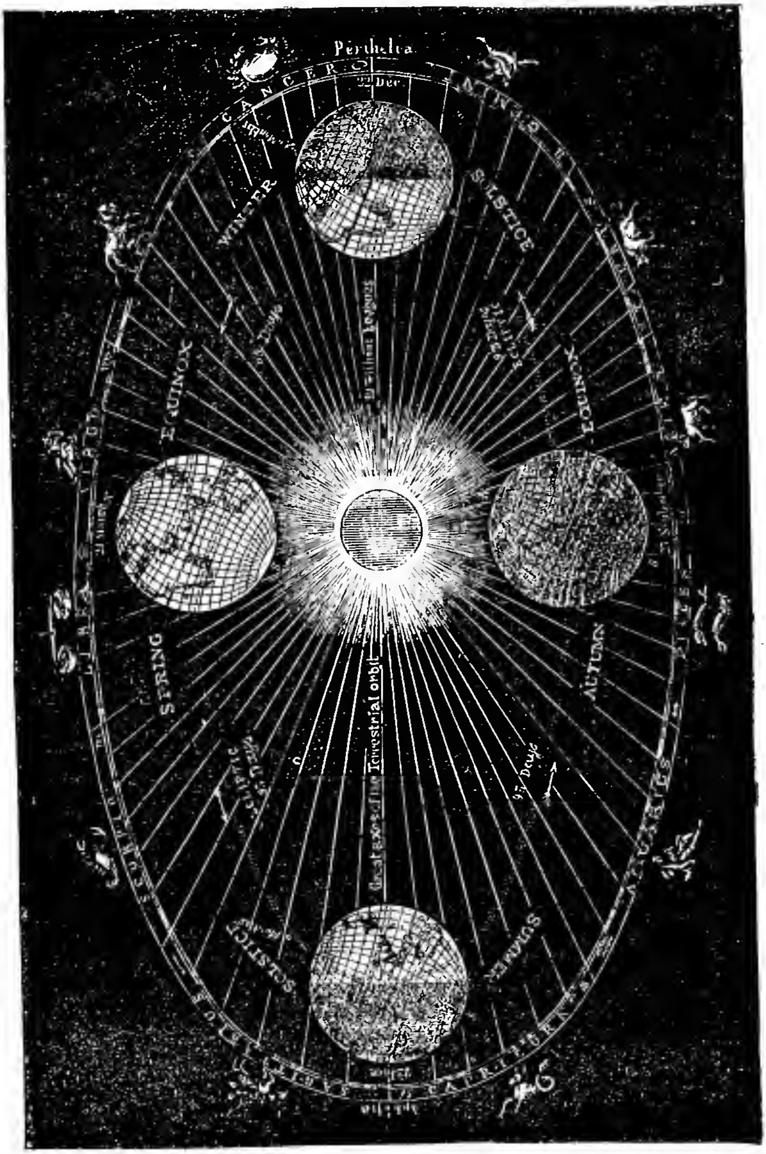


Fig. 34.—Rotation of the Earth round the Sun.

Owing to its rotation upon its axis, each point of the equator travels about 24,000 miles in twenty-four hours, or 16½ miles a minute, which is about the velocity of a cannon ball. This rotation, taking place in the direction of west to east, gives rise to the apparent motion of all the celestial bodies from east to west.

The Earth moves without concussion; its motion is common to both solid and liquid masses, to the air and the clouds, and that is the reason why we do not feel it. We have continually the same landscape before us; the neighbourhood in which we are placed invariably retains the same situation as regards ourselves, and thus it is that we do not remark that we change place relatively to the heavens to the extent of 1,450,000 miles in the terrestrial orbit, and nearly 16½ miles a minute at the equator, borne along as we are by the Earth's motion around its axis.

The Earth's motion in its orbit can only be attributed to the Sun, with which our planet is closely connected, and which exercises its powerful attraction upon it. Its prodigious mass, placed in the centre of our planetary system, keeps up in the bodies around it the impulsion which God gave them in the beginning, and maintains between them that admirable equilibrium without which the world could not exist.

X.

Kepler, the pupil of Tycho-Brahé, discovered the immutable laws of the planetary motions. Born in 1571, at Weildiestadt (Würtemburg), he was one of those rare men of genius who work out the great theories only half prepared by the labours of earlier generations. Upon the 24th

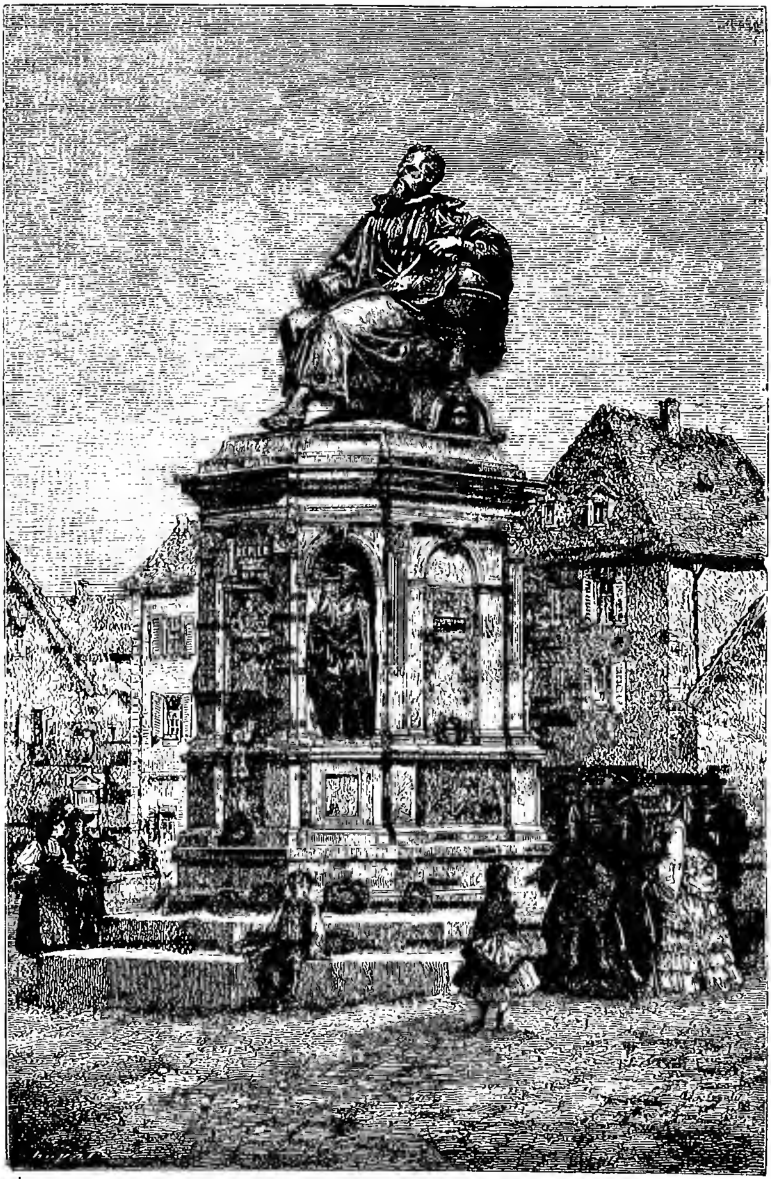


Fig. 35.—Monument erected to Kepler at Weildiestadt, his native town.

of June, 1870, a monument in his memory was unveiled in his native town, which does not count more than two thousand inhabitants. Upon the house in which he was born is the following inscription:—"From this modest dwelling-place came the great Kepler, the father of untrammelled science, who, by the power of his genius penetrated the sublime majesty and the secrets of the Creator. This is why so humble a spot will be celebrated in the ages which are yet to come."

Frisch, who has just terminated the publication of Kepler's complete works, begun in 1854, took for the text of his discourse the words of the poet: "The spot inhabited by a great man is sacred. A century after his death, his words and his deeds still echo in the ears of posterity." I will quote a few sentences of his remarks "Kepler's genius was scarcely appreciated during his lifetime. After the publication of the works which contained his greatest discoveries, he replied to a person who wrote to inform him of a friend's death; 'I have lost my only reader.' And he also wrote these prophetic words: 'I am quite indifferent as to whether my works are read or not during my lifetime. I am sure they will be in a hundred years' time.' Kepler's necessities compelled him to study *astrology*, which he found far more profitable than true science. In one of his letters, he says: 'Where would real *Astronomy* be if she had not a harum-scarum daughter, such as *astrology?* The salary of the philosopher is so meagre, that the mother would starve unless she had the daughter to support her!'

"The voluminous correspondence which he has left is full of interest, for in it we see the man. His works reveal the philosopher; in his correspondence we admire the noble qualities of the father, husband, and son, and his conduct in very trying circumstances. We love and esteem the man who was devoted to his mother, the modest philosopher the same with the great as he was with the lowly, who remained fast to his convictions and earned respect both for his personal and scientific merits."

Upon a raised pedestal of elegant shape is placed a bronze statue, about four feet in height, of the celebrated astronomer. He is represented in a sitting posture, holding in his left hand, which rests upon a celestial globe, a parchment containing the drawing of an ellipse. In the right is an open compass. The four niches of the pedestal are filled with statues two feet high, of Michel Mœsklin, the Tübingen professor who taught him mathematics, Nicholas Copernicus, Tycho-Brahé, and Jobst Byrg, the mechanician who aided him in constructing his optical and astronomical instruments. On the centre is engraved the word "Kepler," and upon each side are bas-reliefs representing various scenes in his life. On the front is engraved *Physica cœlestis*, and beneath is a bas-relief representing Urania measuring space. Upon the right side is inscribed the word *Mathematica*, and underneath is Kepler, at the age of 17, entering upon his studies at Tübingen, under Professor Mœsklin. The latter is holding him by the hand and explaining to him the system of Copernicus, a plan of which is given, and a group of fellow-students is gathered around the Professor. Two other bas-reliefs represent: one, the discussion between Tycho-Brahé and Kepler as to the world's system, in the presence of Emperor Rudolph and Wallenstein, with men engaged in printing the astronomical tables called *Tabulæ Rudolphinæ;* while in the other, Kepler and Byrg, in their Prague workshop, are using their newly-completed telescope to observe the stars. Above these bas-reliefs are engraved the words *Astronomia et Optica.*

XI.

M. Petit, formerly director of the Toulouse Observatory, very truly remarks that, living upon the borders of two centuries, during which the cosmogonic conceptions of the human mind were very strikingly marked out, Kepler, who lighted the torch which was destined to shed such lustre upon the future, could scarcely be expected to escape the prejudices created by the darkness which had gone before. Endowed with an ardent imagination, possessed of an inquiring spirit, burning with the desire to achieve fame, and originally intended for the religious profession, he was distinguished as a preacher at the age of 22; when Mœsklin, his professor, obtained for him a post as mathematical master at Gratz, and induced him to abandon the church for astronomy. Henceforward, led to make researches into the first causes, he endeavoured to find an explanation for every fact, and this is why his first works contain many singular theories. Fortunately for him, Tycho-Brahé, who had settled in Germany after his twenty years' occupation of the Dutch Observatory (see p. 26), discovered the genius of the young astronomer by the very errors which he committed. He procured for him the appointment of mathematician to the Emperor, and induced him to take up his residence at Prague. Thus Kepler was put in possession of the valuable materials which Tycho-Brahé had amassed, and which were of great service to him in after life.

The following lines, written by Kepler himself, will give an idea of the enthusiasm by which he was animated in search of truth :

"*Within the last eight months*, I have seen the first ray of light; within three, daylight; and within the last few days, the Sun, to my great and exceeding wonder. Nothing shall restrain me from indulging in my enthusiasm. I wish to insult mankind by the ingenuous confession that I have spoiled the Egyptians of their gold, in order to create a tabernacle for my God, far from the confines of Egypt. If you forgive me I shall be all the better pleased, but if not, I must endure your reproaches as best I can. *Alea jacta est;* I write my book. It will be read either by the present or by a future generation; I don't care which. It can bide its time. Did not God remain for six thousand years in contemplation of his works! . . ."

The life of this great man was far from a happy one in a material point of view; yet he says "I would not exchange my discoveries for the duchy of Saxony." And he was, of course, quite right. Still he cannot help complaining of "the hard times which prevent the Treasury from effecting a regular payment of his salary as mathematician to the Emperor." It was with a view of obtaining the back payments of this pension that Kepler, after putting up with great privations for eleven years, went from Prague to Ratisbon in November, 1631. But broken down by suffering, mental as well as physical, he was unable to resist the fatigue of the long cold journey upon horseback, and on the 13th of that month he died, far from all his friends, at the age of 60; and his last moments were further embittered by the reflection that the remembrance of his name would perhaps be of small service to the loved ones who survived him. His presentiments, alas, were only too true; and such was the fate of one who has been truly termed "the Legislator of the Stars." *

The concluding lines which Kepler wrote on terminating his works on Astronomy, reveal his great natural piety, while they prove how much real pleasure he derived from his studies. "Before rising from this table upon which I have conducted all my researches, I have but to raise my hands and my eyes towards heaven, and address my humble prayer to the author of all light. O Thou, who by the shedding of light upon nature, dost elevate our desires to the divine light of grace, so that we may be transported into the eternal light of Thy glory; I thank Thee, O Lord and Creator, for all the joy which I have felt in the contemplation of the work of Thy hands. In this book which contains the result of my endeavours to show man the greatness thereof, I have tried to guard against presumption, and, so far as my limited capacities permitted, to fathom the mysteries of infinity." †

XII.

Kepler believed, like his predecessors, that the motion of the celestial bodies must be circular and uniform, and he made several efforts to prove that the motion of the planets was the same, but, after many unsuccessful experiments, he pierced the error which had been committed by previous generations, and arrived at the three important discoveries, since called the *Kepler Laws,* which are based upon the elliptic motion of the planets around the Sun. These laws are so precise that they enable the calculator to name the exact

* Petit's *Treatise on Astronomy,* p. 245.

† *Kengstenbergs ev. Kerched-zig.* 1820, p. 411.

date at which a planet will return to any given point of its orbit.

Kepler, however, was unable to discover the forces which produced the motions he had so accurately defined. He expended great labour upon this task, but it only resulted in speculations far removed from the reality, and it was left for Newton to disclose the general principle of the celestial motions.

Just as all weighty bodies tend to the centre of the Earth, so do the bodies which compose the solar system tend, by force of attraction, towards the sun, which is their common centre. But the planets, if they were governed only by the force of attraction, that is to say, by the force with which the sun attracts them towards him, would gradually be precipitated into that luminary; and Newton found that there were two motive powers with which they had been endowed by God from the beginning.

The first of these is centripetal force, which attracts or carries the planets towards the Sun, their centre; the second is centrifugal force, which causes them to recede from it. These two forces counterbalance each other.

Thus, the Earth, instead of being transported to a great distance from the Sun by centrifugal force, or dashed against it by centripetal force, is maintained in its orbit by the combined action of the two, and made to describe around the Sun an ellipse, of which it occupies one of the foci.

It is to these motions in the heavens that Lamartine's beautiful lines refer:

> Ces sphères, dont l'ether est le bouillonnement,
> Ont emprunté de Dieu leur premier mouvement.
> Avez-vous calculé parfois, dans vos pensées,
> La force de ce bras qui les a balancées ?
> Vous ramassez souvent dans la fronde ou la main
> La noix du vieux noyer, le caillou du chemin:

Imprimant votre effort au poignet qui les lance,
Vous mesurez, enfants, la force à la distance;
L'une tombe à vos pieds, l'autre vole à cent pas,
Et vous dites: "Ce bras est plus fort que mon bras."
Eh bien, si par leurs jets vous comparez vos frondes,
Qu'est-ce donc que la main qui, lançant tous ces mondes,
Ces mondes dont l'esprit ne peut porter le poids,
Comme le jardinier qui sème au champ ses pois,
Les fait fendre le vide et tourner sur eux-mêmes,
Par l'élan primitif sorti du bras suprême,
Aller et revenir, descendre et remonter
Pendant des temps sans fin, que lui seul sait compter,
De l'espace, et du poids, et des siècles se joue,
Et fait qu'au firmament ces mille chars sans roue
Sont portés sans ornières et tournent sans essieu?
Courbons-nous, mes enfants, c'est la force de Dieu.

Newton did not confine his labours to the principal planets; he calculated the motion of the satellites, and the routes of the comets with an accuracy confirmed by subsequent observations. The ebb and flow of the sea, the precession of the equinoxes, the nutation of the Earth's axis, &c., are all effects of attraction and centrifugal force.

XIII.

The Earth is nearest to the Sun about the 1st of January, and furthest away about the 1st of July. In the month of January, the Earth's distance from the Sun is 89,895,000 miles, and in the month of July, 92,965,000 miles. So that there is a difference of nearly 3,000,000 miles. It seems strange that the Earth should be further from the Sun in summer than in winter, yet it is perfectly comprehensible when it is remembered that the heat we receive from the Sun is due, not so much to its proximity as to its elevation above our horizon and the time it remains there. Above the 66th

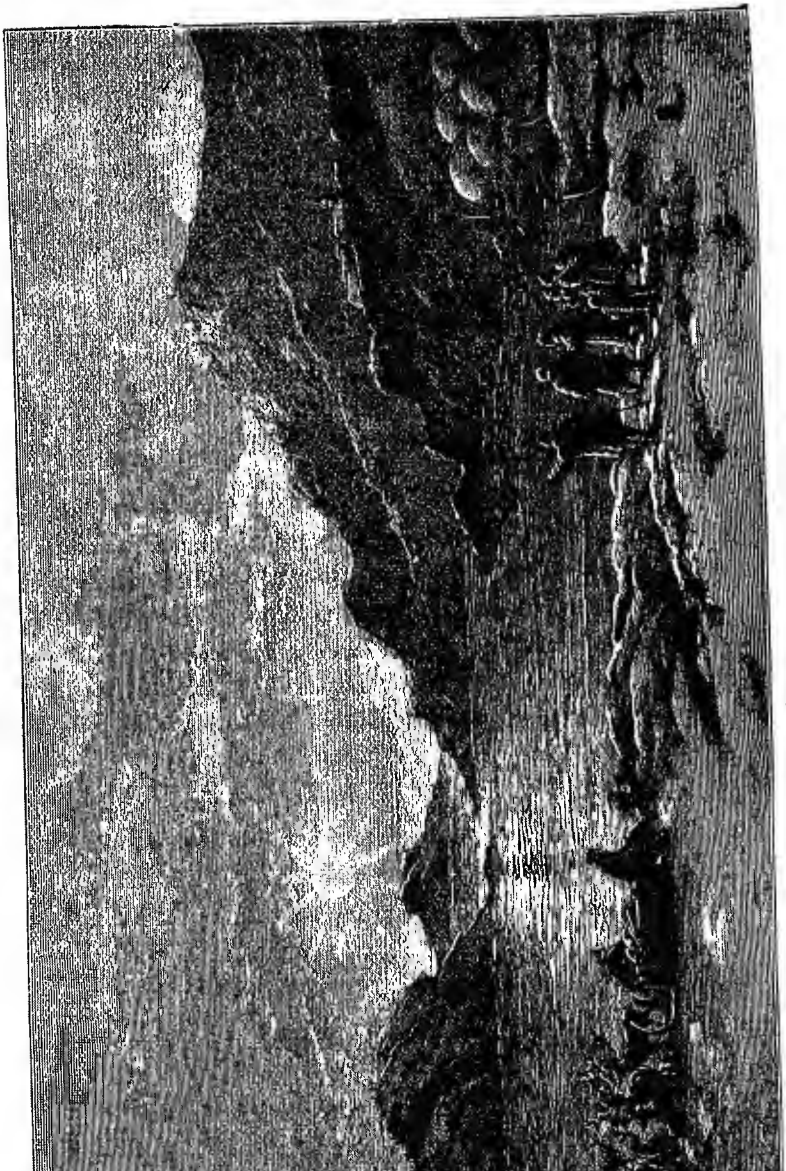


Fig. 36.—The Sun at midnight in the north.

degree, the Sun does not set when it has entered the sign of Cancer. Below the 64th degree, it only disappears at 10.10 P.M., reappearing 50 minutes later, for, though in reality it remains 3 hours and 40 minutes below the horizon, the reflection of its rays upon the mountain-tops, and the light shed upon the horizon by the twilight, enable one to read and write without artificial light.

The inhabitants take advantage of this to shoot and fish all night, while navigators are enabled to pass through the ice floes. Though the sun never sets in midsummer, its light is not so brilliant in the evening as at noon; its brilliancy diminishes correspondingly with its disc, and becomes mild like moonlight, so much so that one can look straight at it without being dazzled.

These countries, which have nightless days, have also dayless nights. In midwinter, the only substitute for the Sun is a faint twilight, emanating from the reflection of the rays which it lets fall upon the lofty mountains and the thick mists that compose the atmosphere of the glacial zone.

The nights are never so dark at the poles as in other regions, for the moon and the stars seem to possess twice as much light and scintillation, while their rays, reflected by the snow and ice with which the ground is covered, shed so bright a glow that one can see one's way, or even read without the aid of a candle.

During the Sun's disappearance, the Moon is nearly always effulgent in these regions, and, in addition to it, there is a continuous light in the north, the varied shades and play of which are amongst the strangest phenomena of nature.

The Sun, with all its varieties of light, presents us with a marvellous spectacle, and I shall never forget the splendour of the sky in the polar regions, with its vast sheets of opal, sapphire, emerald, and ruby, amidst which the Sun, after disappearing beneath the horizon, seems to shed its brilliant glow long after it has ceased to be visible. But I prefer to give the reader, in place of my own impressions, an extract from M. Marmier's introductory speech when he was received a member of the French Academy. He says: "There is a sight in the far North which, though it recurs every year, cannot be witnessed without admiration. In summer time, as night approaches, the Sun gradually sinks towards the horizon. Darkness does not spread itself over the land, but upon the surface of the sky appears a white veil which modifies the light, and a deep silence reigns in the woods, the fields, and the waters. Nature is at rest. Then, all at once, the East becomes bright with purple, the luminous rays reappear, and motion begins again. It is the dawn of one day which follows close upon the footsteps of the other. As I recall to my mind this spectacle which I have so often witnessed in Sweden and Norway, it seems to me that nations, in their summer time, undergo phases when their vital force seems numbed, when the Sun of their glory seems to be departing from them. But, yet a little while, and that immortal Sun, which no ocean can extinguish, no darkness obscure, will shine forth again in all its splendour."

XIV.

Arago, in his work on *Popular Astronomy*, gives an account of the Earth's translation around the Sun, of which the following is an abridgment.

Aristarchus of Samos (280 B.C.), insisted, as we learn from Plutarch, that the Earth moved round the Sun, for which he was accused of impiety.

Cleanthes of Assos (260 B.C.), is said by the same authority to have been the first to explain the phenomena of the starry sky, by the hypothesis of the Earth's motion around the Sun, combined with a rotatory motion of the Earth itself upon its own axis. This explanation, Plutarch says, was so novel and so much opposed to the ideas generally received, that many philosophers were anxious to prosecute Cleanthes for impiety, as had been done with Aristarchus twenty years before.

The planetary system of the ancients, as transmitted to us by Ptolemy, represents the Earth as the centre around which move the seven planets, called the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. But while they looked upon the Earth as the centre of the planetary motions, and itself stationary, the ancients saw that there was a certain distinction between the motions of the planets and the apparent motion of the Sun, but they were unable to disentangle the complicated details of the world's system.

Copernicus, in the sixteenth century, endeavoured to solve the difficult problem by reverting to the ideas formerly expressed by Philolaus, the Pythagorean philosopher, who had maintained that the Earth was a planet circulating round the Sun. In his great work, *De revolutionibus*, Copernicus began by examining whether this opinion was consistent with the results of observation. He found that the hypothesis of the Earth traversing an orbit placed round the Sun, gives a basis by which the relative distances of the planets from the Sun may be accurately determined, and he was enabled to construct a system which will bear the severest scrutiny in all future time. In his system, the Earth circulates round the Sun, taking with it the Moon as its satellite.

To Kepler belongs the credit of having established the true planetary system, following up the ideas of Copernicus, upon the central position of the Sun with the planets circulating around it, and of having abandoned the old hypothesis, as to circular uniform motions around an imaginary eccentric point void of all matter. He also dismissed as illusionary the supposed motions in an epicycle, and concluded that the Sun is the centre of the planetary motions which take place along the circumferences of ellipses in which it occupies one of the foci. To place this supposition beyond the reach of criticism, and to establish it as an immutable verity, he took infinite pains in the compilation of a vast mass of calculations, based principally upon Tycho-Brahé's observations of Mars. He succeeded in explaining all the peculiarities of motion in that planet which had baffled the efforts of earlier astronomers. Thus he discovered the three great laws which bear his name, and which more recent discoveries have fully confirmed.

XV.

Water occupies three-fourths of the Earth's surface, dry land only a fourth. There is four times more dry land in the Northern than in the Southern hemisphere. The Eastern hemisphere contains the largest extent of land—about two-thirds of its whole mass—so that the sea predominates in the Western hemisphere.

Internal influences have led to variations in the level of the Earth's crust, to which no doubt must be attributed the phenomena remarked in many places. For instance, in Sweden the soil rises about two yards every century above the sea-level; at Ravenna, the floor of the cathedral is several inches below the level of the Adriatic, though when the cathedral was built the reverse was the case; the palace of Tiberius, at Capreæ, is also below the sea-level, and at Cadiz the temple of Hercules, now submerged in the sea, is only visible at low water. The surface of the Earth is studded with rugosities, elevations, depressions, horizontal tracts inclined in different directions, &c. At first sight one is scarcely able to conceive the harmony which the contexture of the terrestrial crust, external as well as internal, displays to an experienced observer. It might be supposed that if there was such a thing as hazard in nature, the word might well be applied to the mountains and watercourses, the various mines and rocks. But such is not the case, for they are governed by laws as rigorous as those which direct the stars in their courses.

But it is hardly twenty years since the bases of this science, as simple as it is grand, were laid down, and to the lamented M. Élie de Beaumont belongs the credit of solving the puzzle and tabulating the laws which preside over the position of mountains and the large masses on the globe's surface. Following in the footsteps of one who has been termed the father of modern geology, there is no longer any need to grope one's way, and the details of this science may be grasped with logical accuracy by any one who will take the trouble to study his teachings.*

* *Rapport sur le progrès de la stratigraphie*, by Elie de Beaumont.

XVI.

The embossment of the globe has a great influence upon the climate and the nature of the soil. There are the lowlands, consisting either of plains, undulated ground, or hills and valleys; there are the highlands, consisting of a large extent of elevated ground, to which the name *plateau* has been given, or vast salient masses which form the mountains.

One of the most remarkable features in the high mountains are the glaciers, which are composed of masses of snow that successive frosts and thaws have transformed into ice. Their thickness varies according to their size, often exceeding a hundred feet, while at certain points on the *Mer de Glace*, at the foot of Montanvert, it reaches from 650 to 800 feet. These glaciers form an interesting subject for study, and it appears from a communication of M. Grad to the Academy of Sciences (first half of 1871) that the masses of snow accumulated in the lofty glens of the Vosges undergo the same transformation as glaciers far higher up in the Alps. These accumulations form small glaciers, which do not last very long, though it has been remarked that their stratification corresponds to several successive falls of snow, separated by intervals of milder weather. Their transformation is caused by the fusion of the snow on the surface, which, filtering into the mass, gradually changes it into ice, more or less compact at the surface of the soil. All these changes impart to the small glaciers a temporary propelling motion, similar to that of the large glaciers. This motion, appreciable even in the glaciers where there is but a slight declivity, causes a transfer of the

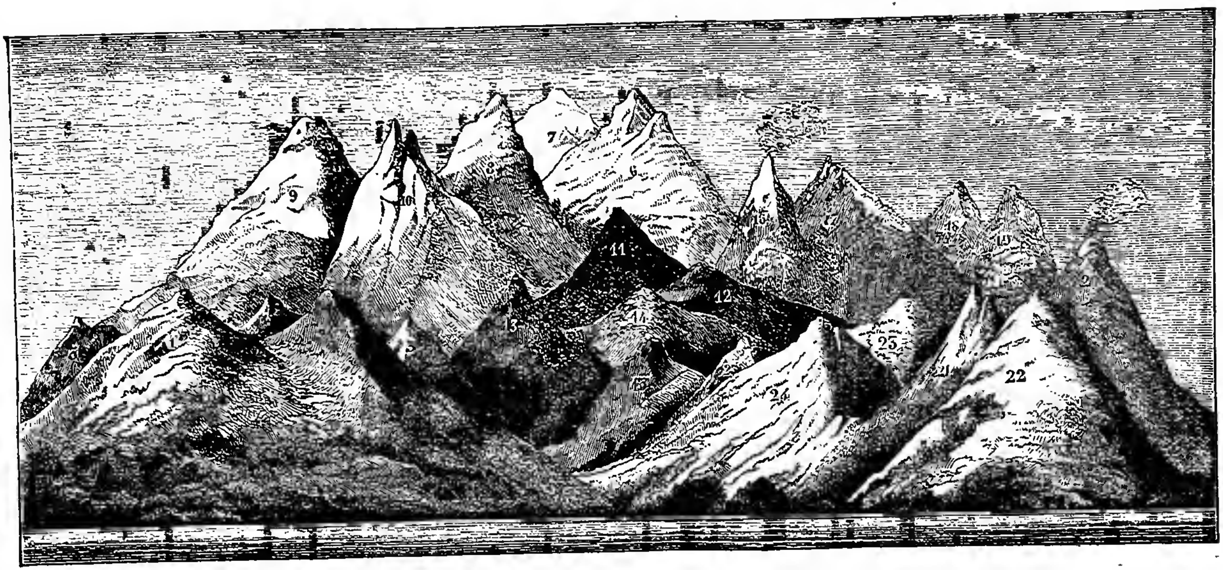


Fig. 37.—Height of principal mountains above the level of the Ocean.

EUROPE.—1.	Mont Blanc	4·810 m.
,, 2.	Mont Rose	4·630
,, 3.	Finsteraahorn	4·360
,, 4.	Mont Cervin	4·522
,, 5.	Mont Géant	4·206
ASIA.—6.	Gaurisankar	8·840 m.
,, 7.	Tchalamari	8·700
,, 8.	Dhawaligiri	8·556
,, 9.	Thsour	8·473
,, 10.	Djamahir	7·847
AFRICA.—11.	Kilimandjaro	6·100 m.
,, 12.	Wosho	5·060
,, 13.	Kenia	5·000
,, 14.	Ras Dajan	4,620
,, 15.	Camerones.	3·780
AMERICA.—16.	Aconcagua	7·299 m.
,, 17.	Nevado d'Illimani	7·274
,, 18.	Sahama	6·810
,, 19.	Chimborazo	6·527
,, 20.	Cotopaxi	5·755
OCEANIA.—21.	Peak of New Guinea	4·870 m.
,, 22.	Mouna Roa	4·840
,, 23.	Mons Carfak	4·300
,, 24.	Mount Ophir	4·220
,, 25.	Mount Simirou	3·898

maximum of thickness from the upper to the lower portion of the mass during the interval between spring and summer. Thus the Vosges glaciers present upon a small scale the same transformations as those in the Alps, except that their transformations are more rapid, because of the more elevated temperature. They are, in fact, almost at an end in the Vosges, when they are only just beginning in the upper regions of the Alps; as for instance, on the Col Théodule, where, at an altitude of 9,900 feet, the glacial embryo, when submitted to experiment, is found not to begin its transformation until June. A remarkable fact in connection with the glaciers, which must have been noticed by all travellers to Chamounix during the summer, is the progressive diminution of the two principal glaciers in that valley, the Mer de Glace and the Glacier des Bossons. Persons returning to Chamounix after an absence of ten or fifteen years, have remarked a great change, and the observations extending over a period of forty years, taken by a resident, prove that, with the exception of partial oscillations, probably due to the severity of particular winters, the same phenomenon has been going on for the whole of that period.

The diminution of glaciers on the northern slope of Mont Blanc forms a striking contrast to the encroachment of the glaciers on the northern slope of Mont Rosa.* The coexistence of these two facts leads to the supposition that the oscillation of the glaciers is mainly due to local causes, engendering either a decrease or increase of temperature. Nevertheless, the contraction of the Chamounix glaciers seems to be merely an instance of the elevation of temperature which is said to have taken place within this gene-

* M. Rey de Morande, and the *Académie des Sciences*, 1869.

ration throughout various districts of Upper Savoy. Abbé Vaullet, after forty years of thermometric observations, regularly repeated twice a day, and by studying the growth of plants, arrived at this conclusion so far as the neighbourhood of Annecy was concerned, and he attributed the change first to the clearing of forests; secondly to the cultivation of waste lands; thirdly, to the opening up of roads; fourthly, to the removal of so many hedges.

XVII.

M. Grad, in a further communication to the Academy of Sciences upon the limits of perpetual snow, makes some valuable contributions to our stock of knowledge. Bouguer states that this limit corresponds, all over the Earth, to the height at which the *mean annual temperature* stands at zero (centigrade). Alexander von Humboldt and Leopold Buch fix the limit at the *mean temperature of zero* (centigrade) *during the summer;* and M. Renou affirms that in all countries the limit of perpetual snow is the altitude where, during the warmest half of the year, the mean temperature equals that at which ice melts.

M. Grad insists that what little positive information we have is insufficient to permit of our establishing relation between the temperature of the air and the lowest limit of perpetual snow.

The observations taken in various parts of the Alps incline him to think that the *line of névés,** as indicated by Hugi, who was the first to study this question, is most likely to be the lowest limit of perpetual snow.

* *Névé* is a substance half snow, half ice.

Névé is snow in a grainy condition, partially transformed into ice, and forming upon the surface of glaciers a series of successive annual strata, the outlines of which are easy of recognition. The contour of the most recent stratum constitutes the lowest limit of perpetual snow, the precise altitude of which has only been measured at a few points, and the figures given in the works on geography must only be taken, therefore, as approximative. In the Alps the mean height is from 3,300 to 3,630 yards in the Alpes Maritimes and the Alps near Cotte; 3,080 on the northern, and 3,520 on the southern, slope of the Valais Alps; 2,860 or 2,970 in the Glarus Alps.

In the Scandinavian Alps, where the temperature is higher, and upon the western slope, which is also exposed to mild winds, the snow-limit, at 67 degrees latitude, is as little as 1,100 yards; and upon the eastern, which is both drier and warmer, it is only 1,320 yards. Upon the southern slope of the Himalayas, comparatively warm and wet, perpetual snow has a limit of 5,745 yards; and upon the eastern slope, which is both colder and drier, it is 6,130 yards. Such is also the case on many other points of the globe. The lowest limit of perpetual snow does not, as M. Grad points out, depend merely upon the temperature, for it varies very much in the same latitude, according to the amount of snow-precipitations. The highest limit is 6,812 yards, upon the southern slope of the Kara-Koroum mountains in the interior of Asia, between 35 and 36 degrees of N. latitude. Its lowest is 5,600 yards, in the Andes near Quito, upon the equator. Upon no point of our globe does the limit of perpetual snow reach the level of the sea, not even in the regions where the climate during the warmest half of the year is below zero, as in Greenland or

Spitzbergen. The glaciers alone descend to the level of the sea, in 48 degrees of latitude, in Patagonia, and in 60 degrees latitude on the western coast of America; and this is owing to the great precipitations of snow which are caused by the moist winds.*

The tropical countries containing high mountains possess a very varied type of beauty, for they may be said to enjoy all the four seasons simultaneously. Upon the summits of the mountains glitter ice and snow, while at their feet prevails a tropical heat, so that in the course of a quarter of an hour's walk there is a marked change of temperature. The inhabitants profit by this valuable disposition of nature, to have houses at two or three different altitudes, by which means they can enjoy perpetual spring.

XVIII.

Three-fourths of the Earth's surface are a vast sheet of salt water. The presence of the salt is accounted for by the supposition that the waters once covered the whole globe, and thus dissolved all the saline masses upon its surface. It has also been attributed to the presence of inexhaustible salt-banks in the bed of the ocean.

Sea water, transparent and colourless when a small quantity is submitted to examination, is very varied in colour when looked at in a mass. At one moment its tints are azure blue, at another emerald green. It exhibits, too, all the colours which can be comprised between these two tints: dark blue, grey blue, green blue, dark green, pale green, etc.—the latter colour being especially remarkable all along the Needles.

* *Académie des Sciences*, March 24th, 1873.

The explanation hitherto given of the cause which gives rise to this diversity of tints has been very unsatisfactory, but it is certain that they are produced by matters of various kinds which the ocean holds in suspension.

The phenomenon of the sea's phosphorescence is one of the most beautiful in nature. When manifested in all its

Fig. 38.—Nereus, the Sea-god. Panofka. Blacas Museum, plate 20.

splendour, the surface of the ocean is as magnificent as that of the starry sky.

XIX.

The mysterious depths which separate the continents of our globe are almost unexplored, and the science of marine geography is yet in its infancy. We cannot carry our investigations far beyond the coast without meeting with difficulties as yet insuperable. Still, by means of sounding, considerable results have been achieved, and during a voyage from Rio Janeiro to the Cape, in October, 1852, the sounding-line attained a depth of 46,230 feet. In deep water it is difficult to reach the bottom, but the English Channel has been so completely sounded, that navigators know every inch of it. But the friction of the water, and the weight of the cord itself, make it impossible to tell exactly when the sound touches the bottom. Moreover, the cord does not descend in a straight line, being carried in different directions by the influence of the under-currents. Thus it is impossible to rely very closely upon the results obtained, and it may even be wisest to discard altogether the result of certain soundings in the Atlantic which attained incredible depths.

The system now adopted by the American Navy seems at once the simplest and the most accurate. A cannon-ball is thrown into the sea, attached to a very thin cord. The cannon-ball sinks with a gradually increased velocity until it reaches the bottom. The cord will continue to unroll even after the cannon-ball has reached the bottom, being borne along by the powerful currents. Still, as the speed of these currents is a known quantity, and incomparably less than that of a cannon-ball projected from a great altitude, any hydrographer is capable of distinguishing between the two periods, and so of telling when the action of the cannon-ball upon the cord ceases. This cannon-ball is so constructed that when it reaches the bed of the sea it unfastens itself from the cord, which brings up a small cylinder containing substances from the bottom. In this way, specimens can be obtained from very deep parts of the ocean.

Nature seemed to indicate Ireland and Newfoundland as the two starting points of the line which was to unite the continents of which they form the advanced sentries, and the study of hydrography led to the same conclusion. The bed of the sea sinks very rapidly on leaving the Irish coast, but it soon reaches a depth which varies very little most of the way across. This marine plain, called the *telegraphic plateau*, is about 9,900 feet below the level of the ocean. More level and vaster than the steppes and deserts of our continents, the sound has not discovered there either sand

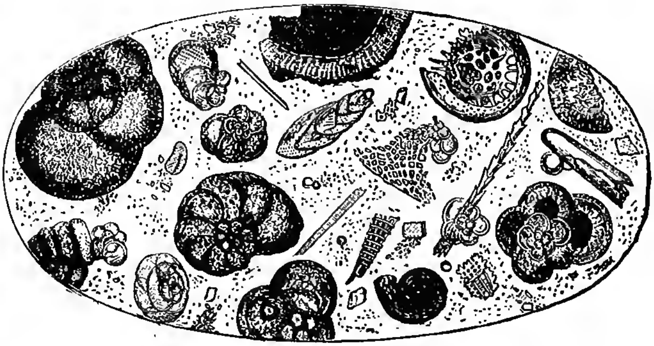


Fig. 39.—Foraminifera, brought up from the bed of the ocean during the laying of the Transatlantic Cable.

or clay, and it is composed entirely of the microscopic animals known as *foraminifera*. These animalculæ, which, during their ephemeral existence, cover the warm waters of the tropical seas, sink after death to the bottom, and the submarine currents carry them to these still depths, where their delicate carapaces are perpetually shielded from the tempests which convulse the surface of the waters.

The bed of the sea, which, in the middle of the Atlantic, is 9,900 feet deep, gradually rises on nearing America until Newfoundland, where it forms a steep decline, as upon the Irish coast.

XX.

In another work, *Les Mondes Scientifiques*, I mentioned some curious experiments which had been made at Wharf-

Road Dock, London, for the purpose of ascertaining the effects of the pressure upon a cable submerged in the Atlantic to the depth of two and a quarter miles. The experiments were made with Reed's hydraulic press, which is capable of exercising a pressure of about 10,000 lbs. to the square inch. The cable used was a piece of that which has been laid in the Gulf of Persia, with a covering of gutta-percha a centimetre (two-fifths of an inch) thick. It was subjected for an hour to a pressure equal to that of a body of sea-water two and a quarter miles deep, Professor Thomson having previously tested its conductibility with a reflecting galvanometer. Some electricians expected that this enormous pressure (5,000 lbs. to the square inch) would force the water into the interior of the cable, and that it would consequently be deteriorated, if not destroyed. The experiment did not warrant these forebodings, for it was found that the pressure had, on the contrary, improved the cable, at least so far as its conductibility was concerned.

It is said that a bottle of wine, carefully corked, was plunged to a great depth in the Atlantic, and that when it was drawn up the wine had all disappeared, and its place taken by salt-water. Also, that a carefully-corked empty bottle was let down, and drawn up full of water without the cork being removed.

In another experiment, six bottles of pale ale, all carefully corked and covered with capsules, were let down; as also a number of bottles of lemonade and ginger-beer, with wire over the corks, like champagne. In one of the empty bottles was placed a wooden cylinder, resting on the bottom and supporting the cork. All these bottles were submitted for an hour to the pressure of a column of water two and a half miles deep. When drawn up, the pale ale bottles were found to be unchanged, as also were the lemonade and ginger-beer bottles. The small space that had been left between the cork and the liquid was filled up, and this was all. The cork in the first empty bottle had been forced in, and it was, of course, full of water. The champagne-cork in the bottle which contained the wooden cylinder was partially forced in, and it came up full like the rest.

These facts, due to the pressure of the water, are not without their interest and instruction.

I will terminate this section of the chapter on "The Earth" by an account of the coral bank near Haïti, which Mr. Green, the well-known diver, contributed to the *Panama Star* in 1868.

"The bank of coral to which I allude is forty miles long by from ten to twenty wide, and it is one of the most beautiful spectacles which the eye of a diver ever contemplated. The depth of the water varies from 10 to 110 feet, and it is so clear that one can see a distance of three or four hundred feet when in the water. The bed of the ocean is, in certain places, as level as a marble floor; at others, it is studded with columns of coral from 10 to 110 feet high, and about a foot in diameter. The summits of the highest columns support thousands of pendants, which are in turn decorated with thousands of still smaller ones. At other points, the pendants form arches upon arches, and the diver, standing upon the bed of the sea and looking through these sinuous passages, is reminded of a cathedral submerged beneath the ocean. Here and there the coral rises to the surface of the water, just as if the loftiest columns were the towers of majestic temples, now in ruins. There is a countless variety of shrubs in every crevice of the coral where the water has deposited any soil. Though of a very faint colour, owing to the small amount of light which they receive, there is every variety of shade, and all of them differ from the plants seen on dry land. One of these shrubs particularly attracted my attention. It resembled a large fan, of very varied colours and tints. The fish upon these Silver Banks are also as varied in shape and dimensions as the region which they move about in, from the symmetrical *goby* to the globular sun-fish, some being of a very dull colour, and others of a hue as changing as that of the dolphin."

XXI.

The temperature of the sea varies, but at the bottom it is generally four degrees (centigrade) above zero, whatever may be the surface-temperature. Such a temperature naturally sets up numerous motions in this vast extent of water, which is incessantly tending to an equilibrium.

It is possible that these motions give rise to the currents which are remarked in the ocean, and which are vast streams whose progress is only arrested by bodies of water denser than themselves. It is also thought that the shape of the land and the attractive action of the Sun and the Moon contribute to produce these currents.

When navigators use the thermometer, they are able to distinguish with ease the great oceanic currents of tepid water which are encircled by the cold waters, and which, flowing back in the track along which they came, form a sort of interminable stream.

In addition to the great currents there are many secondary ones, notably in the seas between the Tristan d'Acunha islands and the Cape of Good Hope. These currents are easy of recognition, for they make the ocean look as if it was divided into bands of different hues, and a vessel passing through them is driven more or less out of the straight course.

The principal of these currents, the only important one in fact that has been thoroughly studied, is that which starts from the Gulf of Mexico, and which extends all along the coast of the United States to the northern region, where its waters still maintain a relatively warm temperature, and create a space of open sea amid the polar ice.

Mr. James Croll has published several works upon this vast marine current, which is known as the *Gulf Stream;* and he has made some interesting calculations as to the quantity of heat which its waters are capable of transmitting.

He estimates that the total volume of the waters composing this stream is equivalent to a canal about fifty miles long and 1,000 feet deep, in which the water moved at a rate of four miles an hour. The mean temperature of this liquid mass, when it flows from the Gulf of Mexico into the Florida Keys, is not less than 18° 3 (centigrade).

It seems certain that these waters, when they return from the north, have a mean temperature of 4° 4^{c}, a diminution, that is, of 13° 9^{c}. Thus every cubic metre of water conveys from the tropics to the north 13,900 *calorics,* representing a dynamic force of 5,907,000 kilogrammeters, at the rate of 425 kilogrammeters to each caloric. By the same calculation, it is estimated that the current must embody 156,900,000,000 cubic metres of water per hour, or 3,766,000,000,000 per day. At this rate, the quantity of heat which the Gulf Stream subtracts each day from the equatorial region amounts to 52,250,000,000,000,000 *calorics*, or 22,250,000,000,000,000,000 kilogrammeters.

Sir John Herschel's and Pouillet's researches as to the quantity of heat transmitted directly by the Sun, show that if a portion of it was not intercepted by the atmosphere, a square yard, exposed to the Sun's rays, would receive per second a quantity of heat equivalent to 237 lbs. But while Mr. Meech has estimated the quantity of caloric intercepted by the atmosphere at nearly $\frac{1}{22}$ of the quantity emitted by the Sun, M. Pouillet puts it at $\frac{1}{27}$. Taking the former calculation, we find that the heat received per second by a square yard of ground, with the Sun at the zenith, is equivalent to a mechanical force of 96 kilogrammeters, 2′. If the Sun remained stationary at the zenith for twelve hours, it would amount to 4,158,000 kilogrammeters.*

In Köhl's *History of the Gulf Stream* it is pointed out that the name of this remarkable Atlantic current dates back to 1748, when the Swede, Peter Kalm, wrote a book of travels, in which he alluded to the *débris* of trees, plants, etc., which were washed from the Gulf of Mexico to the Faroë Islands and Iceland. The first navigator who turned the current to his profit was Alaminos, the pilot of a vessel conveying despatches from Fernand Cortes to Spain, in 1519. For the next two centuries, the American whalers were the only persons who seem to have been acquainted with it, and they, by keeping out of its course during their voyage back from Europe, reached America a fortnight quicker than the English mail-packets. Franklin, when postmaster-general, had a chart of the Gulf Stream executed by these fishermen, and sent it to the English authorities, but they do not seem

* *Les Mondes scientifiques*, 1870, p. 204.

to have placed any reliance upon it. Franklin, too, was the first to take steps for ascertaining the course followed by the current, which he did by finding out in what parts of the ocean the water was warmer than elsewhere.*

XXII.

M. Grad, in a communication to the Academy of Sciences (1871), points out that if the nature of this marine current is understood over the first half of its course, such is not the case in the northern half. Flowing from the Gulf of Mexico into the Florida Keys, it runs parallel with the coast of the United States as far as Cape Hatteras. In this part of its course, the temperature is nowhere less than 25 degrees (centigrade), and is frequently higher, even in winter, when, upon the African coast, of the same latitude, the mean January temperature is only 12 degrees. After leaving Cape Hatteras, the Gulf Stream deviates eastward from the American coast towards Newfoundland, where, at 42 degrees western longitude from Paris, its temperature varies between 19 and 24 degrees (centigrade) from the months of January to July. Its waters then flow in a north-easterly direction, embracing the coast of Europe and the heart of the Polar Seas. But for the Gulf Stream, the climates of England and Germany would be as inhospitable as that of Labrador: the Scandinavian peninsula would be, like Greenland, a mass of ice. The northern part of Norway, where the sun is invisible for a whole month, would be so cold that mercury would freeze there, as is the case in the same parallel in Asia and America; whereas, thanks to the

* Cosmos, 1868, p. 205.

Gulf Stream, the sea at Fauholnn has a temperature of more than three degrees (centigrade) above zero. Thus, the Gulf Stream is a permanent source of heat, which Mr. James Croll estimates as equal to the quantity emitted by the Sun over a surface of five million square miles at the equator.

Following the march of the temperature at the furthest ramifications of the Gulf Stream, the author gives the proportions of the warm current to the limits of the stationary or floating ice between Greenland and the north of Europe for the last two years. The results of frequent soundings show that the Gulf Stream touches the bottom of the Atlantic Ocean between the Hebrides and the Faroë Islands, at 60 degrees latitude, with a temperature of 5° ·3 at a depth of 770 fathoms. A degree further north, between the Faroë and Shetland Islands, the current is only 200 fathoms deep, and the colder water of the polar regions extend beneath it to a depth of 640 fathoms. Further north still, at 60 degrees latitude, Admiral Irmenger found that at 60 fathoms depth there was a temperature of 7° ·5, as against 10 degrees at the surface.

The waters of the Gulf Stream, as M. Grad proceeds to state, then divide into two arms, one flowing northward along the western coast of Spitzbergen, the other eastward along the shores of Nova Zembla. The western, or Spitzbergen, arm reaches as far as 80 degrees latitude in summer, where it has a temperature of two degrees (centigrade). The limits of the Gulf Stream are more clearly defined in winter than in summer, and the motion of the floating ice ceases during the cold season, as out of a hundred avalanches encountered by vessels in the North Atlantic, ninety were met with in the months between April and August, and ten only during the remainder of the year. The tepid waters of

RIVERS OF EUROPE.

Caspian Sea
Black Sea
Black Sea
German Ocean
Baltic Sea
Baltic Sea
Siberian Sea
Mediterranean Sea
Baltic Sea
English Channel
White Sea
Adriatic Sea
Mediterranean Sea
German Ocean
Mediterranean Sea

ASIA.

Blue Sea
Sea of Okotsk
Siberian Sea
Yellow Sea
Bay of Bengal
Do.
Sea of Oman
Persian Gulf
Lake Aral
Persian Gulf
Dead Sea

OCEANIA.

Southern Ocean
Murray
Murray

AFRICA.

Mediterranean
Gulf of Guinea
Atlantic Ocean
Do.
Do
Mediterranean Sea

AMERICA.

Mississippi River
Gulf of Mexico
Atlantic Ocean
Do.
Do.
Pacific Ocean
Mississippi River
Gulf of California
Pacific Ocean
Atlantic Ocean
Do.

Fig. 40.—The principal rivers of the Globe, from the Atlas of MM. Drioux and Op. Leroy (libr. Eng. Belin.).

the Gulf Stream penetrate into the middle of the polar seas as far as 80 degrees latitude to the west of Spitzbergen, and as far as 76 degrees latitude on the western coast of Nova Zembla. In some of the extreme ramifications of the Gulf Stream there are spots where the water is colder, and as it moves slowly there is some difficulty in ascertaining the direction of the currents. But, notwithstanding these difficulties, the fact of the Gulf Stream extending as far as Nova Zembla has been proved by the presence of timber, bamboo-canes, etc., which must have been floated thither from Brazil; as also by the picking up of nets, and other fishing apparatus, drifted from the Loffoden Isles, or Finmark.

In a note to the Academy of Sciences, 1871, M. Marié Davy points out that the meteorology of Europe is regulated by the atmospheric circulation, and by the marine circulation which it engenders. He insists that the main regulator of the climate in France and the neighbouring countries is the aerial stream, known as the *equatorial current*, in its first part, and the *polar current* in its latter part. The efforts of the meteorologist must, therefore, be concentrated upon the study of this great current: its origin, the causes which affect its quantity, as well as the direction and amplitude of its trajectory, and the laws which govern these changes, together with the signs which denote their being about to take place. He must also study the origin, nature, laws, and premonitory signs of the local phenomena which occur within the moving aerial mass, and are the causes of so much variety in the meteorology of Europe; and, lastly, he must study the fluctuations of the Gulf Stream, which result from the fluctuations of the aerial current, and react in their turn upon the latter.

XXIII.

Rivers generally follow the direction of mountains and flow from east to west, though there are few whose course is either northward or southward. Several of the largest rivers—such as the Nile, the Indus, the Po, etc.—overflow their banks at certain seasons of the year. Nearly all the ancient poets ascribed to, these rivers the honours of divinity. Painters and poets alike represented them as venerable old men, with long flowing beards and a crown of rushes upon their heads. Reclining among the reeds, their hand rested upon a pitcher with water flowing from it, the pitcher being more or less out of the perpendicular, according to the rapidity of the river represented. Upon medals these divinities are placed right or left, accordingly as the rivers which they typify flow east or west. Every river had its peculiar characteristic, generally taken from the animals indigenous to its basin, or the fishes in its water.

Fig. 41.—Rhea (from an Adrian medal).

CHAPTER VIII.

THE MOON.

Nature of the Moon—Its size—The light which we receive from it when it is at its brightest—Heat reflected from the Moon; history of the discovery—Shadows, spots, craters, mountains, and extinct volcanoes, observed upon the Moon's disc—Its various motions—Sidereal revolution—Surprising velocity of the Moon's motion—Is it possible for the Moon to fall on to the Earth—Successive applications of the principle of gravity in explanation of the solar system—Problem of the three bodies—Simple and easy experiments in explanation of the Moon's phases—Ashy light—Symbolisation of the Moon; curious passage from Sophocles.

I.

The Moon is, next to the Sun, the celestial body most calculated to arrest our notice, both in respect to its apparent size and the peculiar phenomena which we see during its course.

Though it appears to us much larger than the stars, it is in reality smaller than any one of them, and its apparent size is caused by its relative proximity to the Earth, from which it is distant only 238,793 miles. The diameter of the Moon, which does not always seem to us the same, for this luminary is at one time nearer to us than the other, is 32 minutes; that of the Earth seen from the Moon would be 1 degree 54 minutes. The diameter of the Moon is 2,153 miles; its circumference, 6,500; its surface, only $\frac{1}{13}$ that of the Earth; its volume, $\frac{1}{49}$; its mass, $\frac{1}{88}$. Like the Earth, it is an opaque body, having no light of its own, but receiving and reflecting that of the Sun. We see it at its brightest when it is full, and its light has been calculated even then to be only $\frac{1}{300}$ that of the Sun.

Volpicelli, in a communication to the Academy of Sciences (first half of 1870), gives some interesting facts relative to the heat emitted by the Moon. He says that Melloni was the first to furnish experimental proof of this phenomenon, which Virgil, Dante, Guarini, and other Latin or Roman poets, had denied. Many philosophers, such as Aristotle, Thomas Aquinas, Pic de la Mirandole, and Jerome Cardan among them, asserted the contrary; but in default of the thermometer by which the fact has since been ascertained, they were unable to prove that statement. The English philosopher, Hooke, points out how feeble is the *direct* calorific effect of the Moon upon the Earth. Montanori, of Modena, states that by means of an air-thermometer and a large mirror it was ascertained that the radiation of the Moon caused a rise of *several* degrees in the temperature. But as he does not state how the experiment was conducted, and as the thermometer was during his time still very imperfect, Volpicelli discredits his assertion altogether, and believes that he is justified in saying Melloni was the first to give experimental and incontestable demonstration of the heat of the Moon's rays (March 23rd, 1846).

This discovery was attended with greater difficulties than might at first sight have been expected; for the most sensitive of thermometers, placed in the focus of a mirror or an eye-glass is incapable of manifesting the existence of heat in the solar radiation. The latest experiments of M. Baille, conducted by means of an ingenious apparatus, which I have no space to describe here, corroborated as they are by the experiments of Lord Rosse, Piazzi Smyth, and Marié Davy, show that the full Moon at Paris emits during the summer months the same quantity of heat as a black surface of the same size kept at 100 degrees (centigrade) and 38 yards distance.

II.

The Moon's surface is covered with black spots, which are visible to the naked eye, and which cause reflections of light, varying according to the position of the Moon in respect to the Sun. Seen through a telescope, they are far more numerous, extending all over its surface, and presenting a volcanic character like the crater of Vesuvius, or the hilly ground in the department of Puy-de-dôme (France). Some of these points have the aspect of lofty mountains, chiefly distinguishable by the triangular shadow which they reflect in the opposite direction to the Sun.

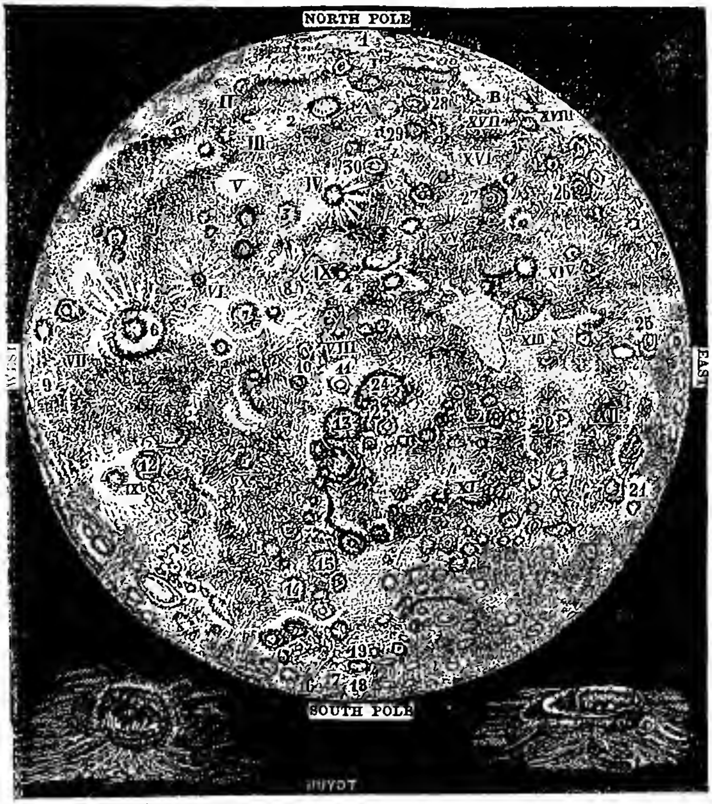
As a general rule the mountains of the Moon seem loftier than those of the Earth. Many of them are thought by astronomers to be twenty-five or thirty thousand feet high, whereas the loftiest of the American Cordilleras is only four miles (22,120 feet) above the level of the sea. At certain times one can distinguish, beyond the limit of the Moon's light, brilliant points, which seem to be detached from its disc, as if they were stars situated close to it. They are, in reality, mountains in the obscure part of its surface, but so lofty that their summits are lighted by the Sun, while their base remains in obscurity.

All these asperities and unevenness of surface explain the indentations often visible upon the bright edge of the Moon. These indentations have often been mistaken for volcanos, though M. de Crety, while watching the eclipse at Aden, on the 18th of August, 1868, believed that he could distinguish, subsequent to the totality of the eclipse, three triangular prominences upon the edge of the Moon, with which they kept close order, and which seemed to be lunar volcanos in a state of activity. Judging from the description given, these prominences must have been gaseous, or at all events formed of very divisible matter. This apparition is not, necessarily, an optical illusion; it has been thought to indicate the existence, upon the posterior surface of the Moon and close to the edge, of a chain of volcanos in a state of activity at the moment of the eclipse, and that their smoke and ashes must have been hurled beyond the edge by some unknown force, with the nature of which we are still unacquainted.

III.

Galileo first attempted to measure the height of the lunar mountains, and his example was followed by many other astronomers, so that their altitude was known even before that of many mountains of the Earth. Hevelius, in his chart of the Moon, adopting the height assigned by Galileo to the lunar mountains, gave to them names taken from geographers, fearing to create a feeling of jealousy if he bestowed upon them the names of rival astronomers, but since that time a different system has been followed.

M. Petit, of the Toulouse Observatory, in his work upon astronomy, says that, after a careful inspection of the shape of the shadows in the Moon, and that of the heights which project them, it is easily seen that most of those heights are composed of a circular enclosure, the inner part of which is generally lower than the mean surface of the Moon,



Crater of Albategnius. *Crater of Eratosthenes.*

Fig. 42 represents the full Moon as seen through a powerful glass. (Guynemer.
Explanation : The capital numbers begin at the top to the left.

Marshes, Seas, Lakes, Gulfs, &c.

I. Glacial Sea.
II. Gulf of dew.
III. Gulf of flowers.
IV. Marsh of fogs.
V. Sea of rains.
VI. Carpathian mounts.
VII. Ocean of tempests.
VIII. Midland Sea.
IX. Sea of clouds.
IX.*b* Sea of vapours.
X. Sea of darkness.
XI. Altai mountains.
XII. Sea of fertility.
XIII. Sea of tranquillity.
XIV. Sea of sleep.
XV. Sea of severity.
XVI. Lakes of dreams.
XVII. Lakes of death.
XVIII. Humboldt Sea.
A. Black Lake.
B. Valley of Endymion.

and in about the centre of which is often noticeable a column (*piton*), which seems to have been formed, like the circular enclosure itself, by matter originally depositing itself in horizontal strata.

These enclosures mostly appear to be of very large dimensions. Some of them, notably those called Riccoli, Ptolemy, Clavius, and others, have diameters of 130 or 140 miles, and it is a manifest proof of their depression that the shadow falling upon their inner surface is generally greater than the shadow which they cast outward. There are few circles of this kind upon this Earth, though there is one at Cantal (France), with a diameter of 33,000 feet, and another in Ceylon, which, though nearly forty times larger than the first, is yet much smaller than several of the lunar circles. Their size may perhaps be due to the fact that as the gravity in the Moon is only a sixth part that of the Earth, the external envelope cannot offer a sufficient resistance, as that of the terrestrial globe does, to the dislocating causes. These circles are connected with the action of

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Fig. 42—*continued.*

Mountains, Volcanoes, Craters, Enclosures, &c.

	Height. metres.
1. Plato, *enc.*	2,210
2. Laplace, *cap.*	3,000
3. Archimedes, *circle*	2,300
4. Huyghens, *mount*	4,500
5. Aristarchus, *enc.*	2,300
6. Kepler	3,600
7. Copernicus, *circle 25 leagues in diameter.*	
8. Eratosthenes, *crat.*	4,780
9. Grimaldi, *hollow.*	
10. Lalando, *mount.*	
11. Herschel	2,900
12. Gassendi	2,900
13. Ptolemy	2,300
14. Longo-Montanus.	
15. Tycho, *circle 70 miles in diameter.*	

	Height metres.
16. Casalus, *circle.*	6,900
17. Newton, *crat.*	7,200
18. Schort, *enc.*	5,940
19. Curtius	6,770
20. Boussingault, *crat., mount.*	
21. Humboldt, *crat., mount.*	
22. Guttemberg *enc.*	
23. Albategnius, *crat.*	4,330
24. Hipparchus, *crests, mounts*	
25. Arago, *encc., mount.*	
26. Geninus, *crat.*	3,700
27. Collipus, *crat.*	6,215
28. Aristotle, *mount*	3,260
29. Eudoxes, *crat.*	4,820
30. Cassini, *mount.*	

central heat, but more as craters of sublevation than craters of eruption.

The Moon, like our globe, presents evident traces of successive geological revolutions. Thus, around several of the circular enclosures there is a second one, very much smaller and evidently formed out of it. In many cases, too, it seems as if the peak or peaks which tower above the large enclosures had been formed subsequent to a primary appearing. The enclosures themselves are generally connected with each other, by lines of hills, as if the subterranean gases had produced in the Moon effects analogous to those observed upon the Earth, and had upheaved the soil between the points where there was a complete disruption.

There is nothing to show that the Moon possesses an atmosphere, and if there was one it would be perceptible during the occultations of the stars and the eclipses of the Sun.

The climate must, therefore, be very extraordinary, passing without transition from a fortnight's heat greater than that of the equatorial regions to a similar period or cold more intense than at the North Pole. It seems impossible that, in the complete absence of air, the Moon can be peopled by beings organised like ourselves, nor is there any sign of vegetation or of any alteration in the state of its surface which can be attributed to a change of seasons.

IV.

The Moon has three principal motions. The first is annual, round the Sun, and is accomplished in the same time as that of the Earth, inasmuch as this motion of the

Moon is but a necessary corollary of the annual revolution of our globe. This motion is analogous to that of a stone placed in a sling, which a person moving very rapidly whirled above his head.

The second motion of the Moon is rotatory, upon its own axis, and is executed in 27 days, 7 hours, 43 minutes, 11 seconds. It takes precisely the same time to accomplish its third motion, which is a revolution round the Earth. Hence it is that we always see the same hemisphere, and that there is consequently only one day and one night in a lunar month.

The Moon circulates incessantly in a re-entering curve, within which is placed the Earth. It never leaves our globe, whence its name of satellite.

The term *duration of the sidereal revolution* is used to describe the time which the Moon takes to come back to a particular star. At the commencement of this century the duration was 2,732 solar days, but it is not the same in every century, having gradually been on the decrease ever since observations were first taken.

Halley first noticed that the motion had been accelerating from the earliest times, notably since the observations taken by order of the Caliphs.

At first sight this seems very astonishing when taken in connection with the laws which regulate the celestial motions, for it is impossible for one body to move around another at greater rapidity without diminishing the distance between them. If the Moon moved more rapidly than the Earth, it must be getting nearer to us, so that if this speed increased to an indefinite extent, the Moon would fall on to our globe and cause terrible revolutions in the present order of things.

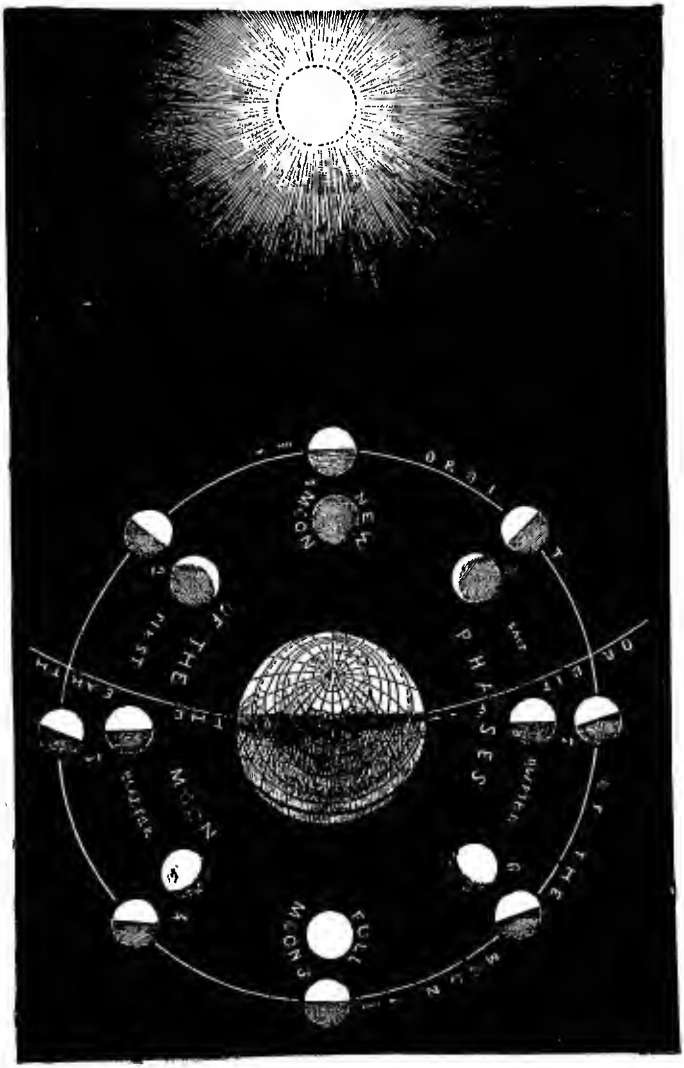

Fig. 43.—The Moon's phases.

The consequences of the acceleration remarked in the Moon's motions were discussed at great length by the astronomers of the eighteenth century, but the public heard nothing of it until Laplace demonstrated theoretically that the acceleration would be confined within very narrow limits, and would be succeeded in the course of time by a corresponding degree of retardation.

Ossian, in a passage of his poem, *Darthula*, also alludes to the popular superstition as to the fall of the Moon to the Earth.

V.

M. Delaunay, writing to the Academy of Sciences, attributes the apparent acceleration of the mean motion of the Moon to the progressive slackening of the Earth's revolution upon itself, owing to the influence of the Moon upon the waters of the sea. In his *Report upon the Progress of Astronomy*, he says: "It was already known that the mean motion of the Moon may be seen to undergo a great change owing to some variation in the rotary speed of the Earth, that is to say, in the duration of the sidereal day, which is the fundamental unity of time in astronomy. I have shown that in the action of the Moon on the sea-water, taking into account the phenomenon of tides, and more especially the retardation of high tide during the Moon's passage over the meridian, there is enough to occasion a progressive slackening of speed in the Earth's rotary motion to an extent that would account for the secular equation of the Moon, which is not to be explained by the theory which Laplace assigned for it."

Little relation as it may at first appear there is between the general temperature of the Earth and the motion of the Moon, the result obtained by Laplace has helped to show that the temperature has not varied the hundredth part of a degree for the space of two thousand years.

Perigee is the point in the orbit of the Moon which is nearest to the earth, as opposed to *apogee*, which is the farthest.

The variations of the Moon's proper motion and the changes in distance are connected by that very simple law discovered by Kepler, to the effect that " the surfaces described by the lunar radius vector are equal at equal times; and from a given radius vector they are proportionate to the times." A *radius vector* is a straight line from the Earth to the Moon. Bouillaud, in explanation of the inequality in the Moon's motion, that great discovery of Ptolemy, attributed it to a displacement of the focus of the lunar ellipse; whence the name of *evection* or *displacement* which has remained to this day.

VI.

I will complete my notice of the Moon by a summary of what M. Delaunay has set forth in his great work upon this subject, from which also we shall be able to deduce the successive applications of the principle of gravity in explanation of the solar system.

Newton endeavoured to establish the identity of terrestrial gravitation and the force which retains the Moon in its orbit round the Earth, but he had not the necessary elements for obtaining an affirmative solution. Picard, a member of the Académie des Sciences, undertook the task of taking an accurate measure of the Earth's dimensions, and by this means he ascertained that the terrestrial radius had been thought much greater than it in reality is. Newton, in 1682, sixteen years after his first essay, heard of Picard's process, which enabled him to evolve the law of gravity (see page 158), by virtue of which "two bodies attract each other proportionately to their masses, and in inverse ratio to the square of their distance." He naturally sought to generalise this law, and see whether it would explain the phenomena presented by the motion of the bodies which occupy space. The Moon furnished him with a means of regulating his inductions. He arrived at the conclusion that if the Sun did not exist, the Moon would revolve round the Earth, while remaining in the same plane of position, that it would describe in this plane an ellipse with one of its foci at the Earth's centre, and that the great axis of this ellipse would not change place with the change of time.

But the Sun, exercising its attractive influence alike on the Moon and the Earth, makes the motion of the former around the latter very different. Newton pointed out that it was this influence of the Sun which causes the retrograde motion of the lunar nodes, the direct motion of its apogee, the nutatory motion of the lunar orbit, and the periodical inequalities which cause the Moon to oscillate right and left from the position which it would occupy if it followed to the letter the laws of elliptic motion.

He also showed that the same law of attraction, which furnished an explanation of nearly all the circumstances relating to the motion of the Moon, accounted in a very natural way for the phenomena of tides, and that this periodical oscillation of the surface of the seas is due to the differences in the action of the Sun, and especially of the Moon, upon the whole mass of the terrestrial globe and the waters which form part thereof.

VII.

M. Delaunay goes on to remark that one of the first questions which the geometers set themselves to resolve was the *problem of the three* bodies; that is to say, given the existence of three bodies, the Sun, the Earth, and the Moon in space, what is the motion of each under the simultaneous action of the other two?

Clairaut, d'Alembert, and Euler each studied this question, about the middle of last century, and each made considerable progress towards its solution. One of the first results which they obtained was the explanation of *evection*—an inequality which Ptolemy had discovered more than nineteen centuries since, and which Newton had failed to make harmonise with his great law of gravity. This inequality, when explained, ceased to form an exception, but became, like the other inequalities which were previously known, a natural consequence of the perturbing influence exercised by the Sun upon the Moon.

The calculation of the perturbations of the planets due to their mutual action upon each other had shown that the elliptic orbit of the Earth slowly alters in shape; that the slight difference now existing between its orbit and a circle is gradually disappearing, or, in other words, that its eccentricity is decreasing. The consequence of this is that a progressive and very gradual change takes place in the annual distances of the Sun from the Earth and the Moon. This change leads to a corresponding variation in the disturbing action of the Sun upon the Moon.

Laplace saw that this must cause a progressive acceleration of the Moon's motion around the Earth, and he found that the sum of the periodic equation due to this cause harmonised with that which had been deduced from a comparison of ancient with modern astronomical observations.

After such successful calculations it was impossible to question the truth of Newton's great law, and so his magnificent conception of an unique cause governing the various motions of the stars as well as the fall of a body to the earth was fully realised. The law of universal gravity became the principal base of the subsequent progress in astronomy, for, previous to its establishment, the researches concerning the motions of the planets were entirely conjectural. This great discovery, establishing a bond of union between all the details of these motions, gradually led up to a more precise knowledge of them, which may be almost indefinitely perfected.

VIII.

The most curious phenomenon and the one earliest observed in regard to the Moon is that of its phases. The theory of the phases is simple, but by means of an experiment that any one can try, it becomes still more so.

If a wooden or cardboard globe, painted white, is exposed to the light of a candle, it will be found that one half of it will be illuminated while the other half will remain in the shadow. The spectator, changing his point of observation in respect to the globe or the candle will see more or less of the illuminated half, and more or less of the half which remains in the shadow, thus witnessing a series of phases similar to those presented by the Moon.

Standing opposite to the candle, only the obscure hemisphere will be visible; starting from this point, and describing a quarter-circumference round the globe, half of the illuminated part, which will look like a semi-circle, becomes visible.

Standing between the globe and the candle in such a posture as not to intercept the rays of the latter, the illuminated half will be visible in full. Making a third revolution of a quarter-circumference, another semi-circle, the reverse of the first, will be visible, and, coming round again to the starting point only the obscure half will meet the eye.

In this way the observer will have seen the four principal phases of the Moon, but if instead of moving round the globe he has the globe moved round him, the phenomena will remain exactly the same, supposing him, that is to say, to turn his body round as the globe is made to revolve.

A still more remarkable effect will be produced if, instead of obtaining the light and shadow from a candle, the experiment is made with a globe of which one half is painted white and the other black. Bearing in mind these phenomena, the following explanations concerning the Moon's phases will be found very easy to follow.

IX.

When the Moon is first seen in the evening, it has the shape of a narrow crescent, the convexity of which is circular and facing the Sun, and the concavity slightly elliptical and facing the east.

The width of the crescent gradually increases; half of the luminous part of the Moon becomes visible at the expiration of seven days, having accomplished a quarter of its course, which occupies twenty-nine days. This is, consequently, the first quarter, and, crossing the meridian at six in the evening, it continues its course eastward, the luminous part becoming larger every day, and appearing to us almost elliptical or oval in shape.

Seven and a half days later, all the luminous hemisphere becomes visible, and this is called the full moon, which rises in the east as the sun sets in the west. It crosses the meridian at midnight. In the interval between full moon

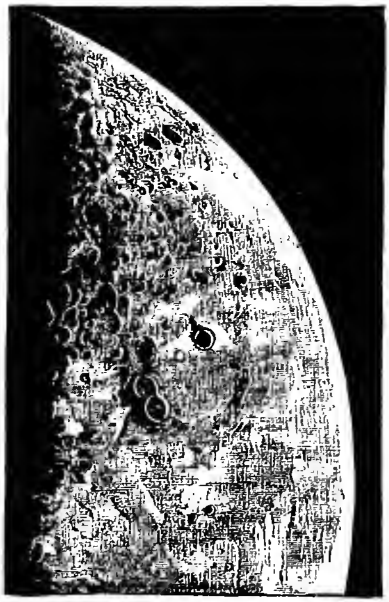

Fig. 44.—The lunar crescent, six days after a new Moon.

and the last quarter, the full moon wanes in exactly the same manner as it had increased; its shape becomes elliptic until we can see no more than half of its disc.

It is then in its last quarter, and does not cross the meridian till six in the morning, and this is why it is visible in the heavens during the greater part of the day. From the last quarter the luminous part continues to decrease until nothing is visible except a crescent, which appears in the east before sunrise, its horns turned up and opposite to the Sun. This crescent then disappears, and is succeeded by a new moon, so called because it comes between the Earth and the Sun, with its luminous hemisphere turned towards the latter.

The faint light shed over all the obscure part of the Moon during the first and last days of the crescents is, like the phases, caused only by the motion of the Moon, and its situation relative to the Earth.

The Earth reflects the light of the Sun upon the Moon, just as the Moon reflects it upon the Earth. So when the Moon is new, the Earth is exactly the opposite (being *full Earth* for the Moon), and transmits it so much light that the Moon retransmits a portion of it by reflection; and hence it is that the whole of the disc becomes visible at dawn and sunset.

Thus the light which passes from the illuminated hemisphere of the Earth to the obscure surface of the Moon becomes reflected, returns in a fainter form to the Earth, and makes visible the half of the Moon, which is not only edged with a silvery crescent, but is of a pale and ashy tint throughout, which causes it to stand out against the azure blue of the sky.

This phenomenon, known as that of *earthshine* (*lumen incinerosum*), ceases as the Moon grows older, for then only a small portion of the luminous hemisphere is turned towards it. Most of these phenomena are indicated in Fig. 43 (p. 193).

X.

M. Janssen, noted for his experiments on spectrum analysis, has published an account of his escape from Paris in a balloon during the German siege, in order to witness the eclipse on the 22nd of December, 1870. The account contains certain passages bearing upon our subject, which are worth record. Leaving Paris at 6 A.M. on the 2nd of December, the thermometer marked 1 degree (centigrade) below zero. The sky was very clear, and after sunrise the thermometer declined to 7 and 8 degrees below zero. Thus, the apparition of the Sun instead of creating an increase of heat, and so of ascension for the balloon, exercised a directly contrary effect, which, strange as it may at first seem, is easy of comprehension. The effect of the solar radiation was to dissipate the atmospheric vapours, to increase the transparency of the atmosphere, and so to augment very considerably the radiation of the balloon towards the celestial regions. In this process the balloon expended more heat than it received from the Sun, and its refrigeration tended to make it descend.

M. Janssen adds: "This action of the first solar rays upon the vapours of the atmosphere, remarked so clearly in the very regions where it took place, is a fresh proof and a very strong one in support of the theory that the Moon is capable of dissipating vapours and light clouds. In this respect the traditions of farmers concerning the April moon, those of the Hindoos as to the agency of the stars in the formation of ice, and other analogous ideas, seem far nearer the reality than scientific men have been inclined to believe. Even if its rays do not freeze plants or congeal water in a direct way, they may nevertheless be regarded as the indirect authors of this phenomenon, if they pierce the atmospheric veil which protects vegetation and sustains terrestrial heat."

The Moon has always been the symbol of capriciousness and change. Sophocles, in a tragedy which has been lost to us, but of which Plutarch cites a fragment, makes Menelaus say: "But my destiny, placed upon the rapid wheel of fortune, is ever revolving and incessantly being transformed. Thus, too, the aspect of the Moon is never the same for two whole nights consecutively. Yesterday it was not visible, but suddenly it begins to show itself; gradually its visage brightens, and expands every day. And, after shining in all its splendour, it begins to wane, and finally disappears." *

* *Life of Demetrius*, p. 173.

CHAPTER IX.

THE ECLIPSES.

Principal eclipses—Occultation—Theory of the eclipses of the Sun and the Moon—Partial, total, or central eclipse—Appulse—Luminous corona, protuberances, prominences, rose-coloured flames noticed during eclipses—The most remarkable solar eclipses—Measure of the eclipses—Immersion and emersion—History of the information about eclipses from what has been remarked during their occurrence—Terror which eclipses formerly inspired—Curious facts—Meton's cycle—The golden number—Saros—Instruments for indicating past and future eclipses—The utility of eclipses in fixing doubtful dates—Historical facts—Christopher Columbus and the islanders—Pericles and his pilot—Pelopidas and an eclipse of the Sun—The soldiers of Paulus Emilius and an eclipse of the Moon—Terror of Nicias, the Athenian general—Remarkable passage from Plutarch.

I.

The principal eclipses are those of the Sun and the Moon. Eclipses of the planets, of their satellites or secondary planets and of the stars also take place, but the latter are generally termed *occultations*.

There is an eclipse of the Moon when, the Earth being interposed between the Sun and our satellite, the latter traverses the cone of shadow that the Earth projects far behind it. For this phenomenon to occur, the Moon must, either at the moment of opposition or full moon, be in the plane of the ecliptic or very near it, that is to say, in or about the nodes.

If the Moon's orbit was parallel to the ecliptic, that is to say to the curve which the Earth describes round the Sun in the course of a twelvemonth, there would be a complete eclipse whenever the Moon was full, but as the lunar orbit is inclined rather more than 5 degrees to the plane of the ecliptic, the Moon is sometimes above and sometimes below that plane. It may, therefore, happen that, when full, it will pass quite beyond the Earth's shadow, or merely graze it with its edge (this is termed *appulse*), or there may be a *partial eclipse*, which means that the Moon traverses part of the shadow. The eclipse is *total* when, at the moment of the opposition, the Moon is in the node itself, and is consequently plunged altogether into the shadow. The eclipse is central when the centre of the Moon coincides with the axis of the cone of the shadow.

During an eclipse the Moon's disc is successively deprived of the light from the various parts of the solar disc; thus its brightness diminishes gradually, and is only extinguished when the disc is completely buried in the terrestrial shadow.

As the Moon is not luminous of itself, and only shines when it is illuminated by the Sun, it follows that whenever, in its circular motion round the Earth, it is in a position where the Sun's light cannot reach it, it must disappear from view or become eclipsed.

As the Earth is an opaque body, it projects opposite to the Sun a cone of shadow which the light of this luminary cannot penetrate. The top of this cone extends to an immense distance—three times that of the Earth from the Moon. The eclipse of the Moon is visible throughout all the terrestrial hemisphere turned towards it.

The *penumbra* is the subdued light witnessed during the gradual diminution.

There are never more than seven eclipses in a year, and never less than two. When there are only two, they are always eclipses of the Sun. The eclipses of the Moon are less frequent than those of the Sun, and sometimes there is

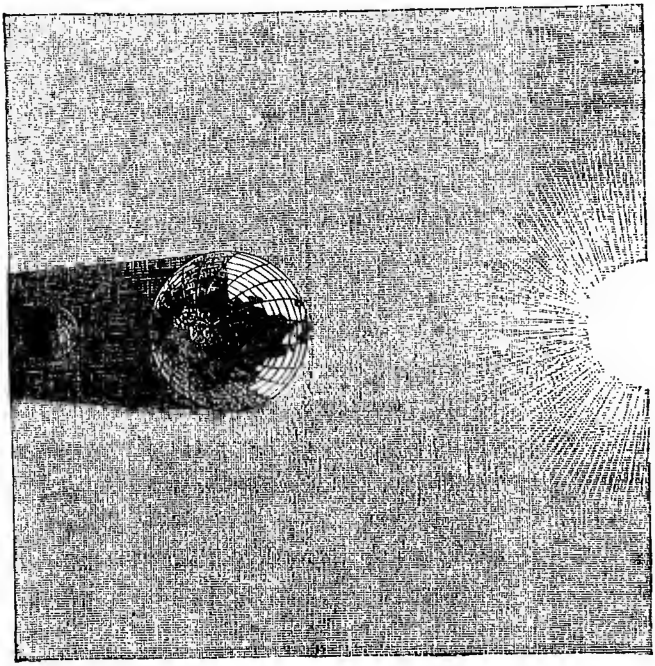

Fig. 45.—Eclipse of the Moon.

not a single one during the year, as in 1763, 1767, 1788, 1789.

II.

The solar eclipses are produced by the interposition of the Moon between the Sun and the Earth, when the Moon is new, that is to say, when it is in conjunction with the Sun.

The solar disc is contracted upon one side, and the obscure part increases in volume, gradually diminishes, and then resumes its normal appearance.

Sometimes the obscurity extends to the whole disc, and the Sun disappears altogether; sometimes, too, there is a large spot projected upon the Sun, with a luminous ring.

It is worthy of notice that solar eclipses only occur at the epoch of new moon or conjunction, while lunar eclipses only take place at the epoch of full moon or opposition.

The distance of the Moon from the Earth is so relatively small that its apparent diameter, incomparably smaller than that of the Sun, seems to us quite as large and sometimes even larger.

When the Moon in its conjunctions is so near its nodes as to be almost in the plane of the ecliptic, the cone of shadow which it projects reaches the Earth, first touches it at a certain point, then traverses and finally leaves it after a certain interval of time. Thus, those parts of the Earth comprised within the space traversed by the lunar shadow see the eclipse of the Sun in succession.

The solar eclipses are *partial, total,* or *central; partial* when the Moon only conceals a part of its solar disc; *total* when the whole disc is hidden (and it is worthy of note that the same eclipse may be *partial* in one place and *total* in another); *central* when the spot from which they are observed is the centre of the shadow, on the straight line which joins the centres of the Sun and the Moon.

In the annular eclipses, the solar disc entirely overlaps that of the Moon, and has the appearance of a luminous ring.

When the discs of the Moon and the Sun merely touch during their passage, there is an *appulse* as it is termed.

The size of partial eclipses is generally calculated by taking as a measure of the eclipsed part twelfths of the diameter of the eclipsed body; these have received the name of digits, and they are subdivided into 60 minutes.

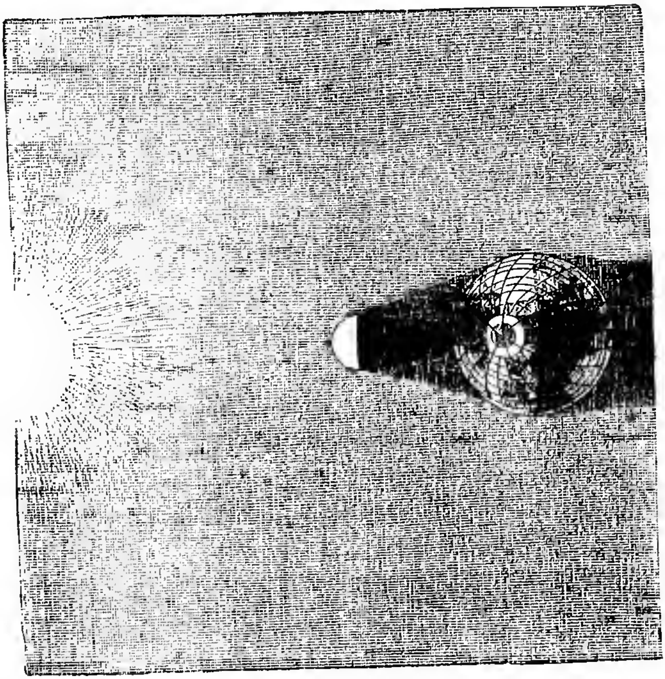

Fig. 46.—Eclipse of the Sun.

The *moment of immersion* is when the edge of the Moon commences to encroach upon that of the Sun, or of any other body which it is about to eclipse. *Emersion* is when the last portions of the Moon move clear of the body which has been eclipsed by it.

In a lunar eclipse, immersion is the moment when the luminous part of the Moon enters the cone of shadow, emersion when it emerges from the cone.

III.

During total eclipses of the Sun, the Moon is surrounded by a luminous corona, which seems to be of a silvery hue. This colour was very brilliant during the eclipse of July, 1842, being composed of a circular zone contiguous to the Moon's edge, and of a second zone, less bright, bordering upon the first. The light of this second zone became weaker from the inner to the outer part, while that of the first was about uniform.

When the sky is very clear, the corona has an extent equal to the diameter of the Moon, but it is only brilliant within far narrower limits. The corona often emits rays or tufts of considerable length, and, taken altogether, is the most remarkable phenomenon of the eclipse visible to the naked eye.

Under the same circumstances, reddish protuberances are to be seen at various points of the Moon's surface, and they are generally classified as prominences, protuberances, flames, clouds, and mountains. The result of M. Clery's observations at Gothenburg showed that the protuberances on the western edge became more salient after the eclipse began; that a protuberance, invisible at the commencement of the eclipse, took form as the eclipse progressed, whereas the easterly protuberances contracted and finally disappeared. M. Arago holds that these protuberances are neither mountains nor apparitions caused by a deviation of the solar rays in the uneven surface of the Moon's edges, but that they are to be explained by the hypothesis of clouds floating in the diaphanous atmosphere which surrounds the photosphere of the Sun.

During the eclipse of July 8th, 1842, the attention of astronomers was attracted by these protuberances or prominences, which are visible during total eclipses of the Sun, and which dart around the Moon like gigantic flames, of a rose or peach coloured tint.

Father Secchi concludes that the prominences are masses of luminous matter, possessing great vivacity and powerful photogenic action; that there is a mass of protuberance-producing matter suspended isolated, like clouds, in the atmosphere, and that there is a zone of this matter entirely surrounding the Sun. The prominences, according to him, are produced by this stratum, and rise above the general surface, from which they even become detached at times.

Some of them resemble the smoke which issues from a chimney, or the crater of a volcano, and which, when it reaches a certain height, is influenced by a current of air and takes a horizontal direction. The number of protuberances is incalculable, they being at times so numerous that it is impossible to count them, and they also vary very much in altitude. Some have been remarked with an altitude three, six, and even ten times that of the earth's diameter; but, as a general rule, they are from three to six times its diameter. M. Janssen having succeeded in studying the protuberances by spectrum analysis, ascertained that hydrogen is the main element in their composition, and his observations have been confirmed by subsequent experiments.

IV.

Amongst the most remarkable solar eclipses in France was the annular eclipse of 1764, visible at several places, and lasting 5 hours, 29 minutes, 30 seconds. A similar eclipse was observed at Paris on the 9th of October, 1847. But the finest eclipse of the present century, so far as Paris was concerned, took place on the 15th of March, 1858, beginning at 11·21 A.M. It was at its culminating point at 1·11 P.M., and terminated at 2·28 P.M. This eclipse was eagerly looked forward to, as an opportunity for trying new instruments and making fresh experiments. The aspect of the sky was not very favourable for the purpose, but still many useful observations were taken. Fig. 47 represents several photographs taken by M. Porro, director of the Technomathical Observatory, and M. Quinet, of the phases of this eclipse.

The eclipse of August 18th, 1868, was visible in Eastern Africa, upon the shores of the Red Sea, in Arabia, China, Madagascar, Ceylon, and Australia.

The Moon was emerging from a perigee unusually near to the Earth, and passing through the upper node of its orbit. Hence it followed that the Sun at its eclipse was very close to the zenith in those countries where the eclipse occurred at noon. Consequently, the diameter of the Moon was very large, and the motion of the shadow extremely slow.

The maximum duration of the total eclipse was in the Gulf of Siam, where it lasted 6 min. 50 sec., the Sun being only 2½ degrees from the zenith. The total eclipse of 1868 was one of the greatest that ever took place. Never, in the memory of man, had an eclipse lasted so long, and only two were to be compared to it in point of size—these were the Thales eclipse, upon the 28th of May, 585 B.C., and that observed in Scotland on the 17th of July, 1843, which was long spoken of as the *Black Hour*. Those who went to India, M. Janssen amongst others, to witness the eclipse of 1868, were rewarded for their journey, as immediately after the total eclipse two magnificent protuberances appeared, and, on examining their light through the spectroscope, they

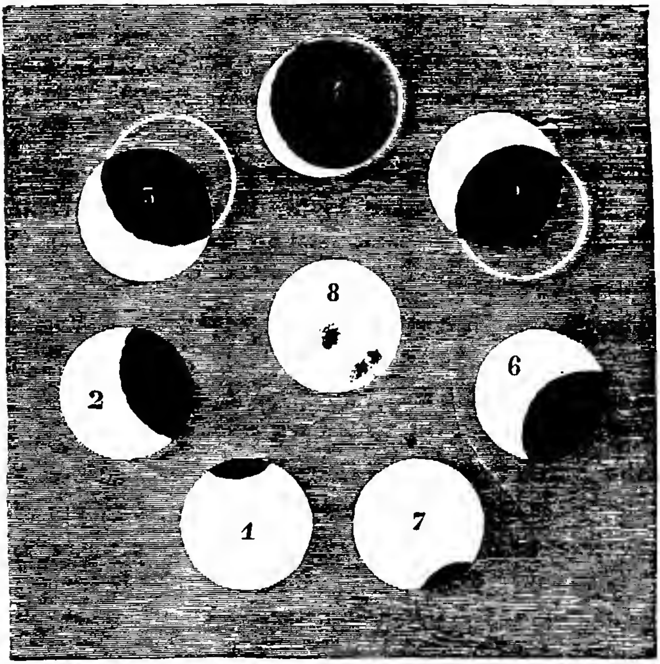

Fig. 47.—Eclipse of the Sun, March 15th, 1858.

Nos. 1, 2, 3. Crescent phases.—No. 4. Maximum phase.—Nos. 5, 6, 7. Waning phases.—No. 8. The spots observed on the Sun a week after the eclipse.

In Nos. 3, 4, 5, the edge of the Moon is seen protruding beyond the Sun.

were found to be composed of two immense gaseous and incandescent columns, in which the element of hydrogen was predominant.

But the most valuable discovery resulting from these observations was the method, hit upon by M. Janssen at the very moment of the eclipse, by which the protuberances and circumsolar regions might be studied at any time. This method is based upon the spectrum properties of the light of the protuberances—a light which resolves itself into a small number of very luminous beams, corresponding to the obscure beams of the solar spectrum. In the interval between the 19th of August and the 4th of September M. Janssen collected a large number of facts bearing upon this subject. But the original conception of this method belongs not to him, but to Mr. Norman Lockyer who, having first lighted upon it in 1866, was working it out in London at the very time that M. Janssen was engaged upon the same study at Guntor in India.

V.

The general phenomena of a total eclipse have been thus graphically described by Father Secchi. "The really interesting features of an eclipse do not begin until the centre of the Sun is covered by the Moon. The light then diminishes very perceptibly, and as the moment of the total eclipse approaches, the decrease is so rapid, that it almost creates a feeling of terror. What is most striking is not so much the diminution of light as the change in colour of the surrounding objects—everything assumes a sombre and gloomy hue. The bright green of the meadows becomes grey, and the highest regions of the sky near the Sun have a leaden colour, while near the horizon the sky is a sort of yellow-green. The human face takes a cadaverous colour, like that produced by the flame of alcohol steeped in chlorure of sodium. This yellow tint, coupled with the decline in temperature, seem to indicate a diminution of the vital forces of nature.

"Accompanying this, there is a general silence in the atmosphere. The small birds seek shelter, the insects disappear, and everything seems to indicate a coming catastrophe. As Mr. Forbes remarks, it is easy to understand how uneducated people are struck with terror at such a spectacle, and look upon it as the forerunner of everlasting darkness. Father Faura tells us that, during the last eclipse, in 1868, vast numbers of the Chinese took refuge upon their junks, to escape a disaster which, notwithstanding the presence of astronomers with their instruments of observation they could not be persuaded was imaginary."*

It is easy to follow the progress of the total eclipse. The crescent wanes with astonishing rapidity, and is soon reduced to a thin thread, terminating in almost imperceptible points, which in their turn vanish. Then the scene undergoes a sudden and complete change, and a very black disc, surrounded by a magnificent gloria of silver rays, with jets of rose-coloured flames glittering amongst them, stands out against a leaden sky. This spectacle, at once beautiful and portentous, is well described by Baily, who says:—

"I was engaged in counting the oscillations of my chronometer, in order to fix the exact moment of the total disappearance, while a vast crowd filled the streets, to witness the phenomenon offered to their admiring gaze. Suddenly, as the last ray disappeared, a loud shout went up from the immense multitude. An electric thrill went through me, and, looking upwards, I saw the most beautiful spectacle which the imagination can conceive. The great orb of day was replaced by a disc as black as pitch, surrounded by a brilliant gloria, such as we see in pictures around the head of a saint.

* Father Secchi on *The Sun*, p. 144.

"Lost in astonishment, I wasted a few of the precious moments, and almost forgot the object of my journey. From the descriptions which I had previously read, I was

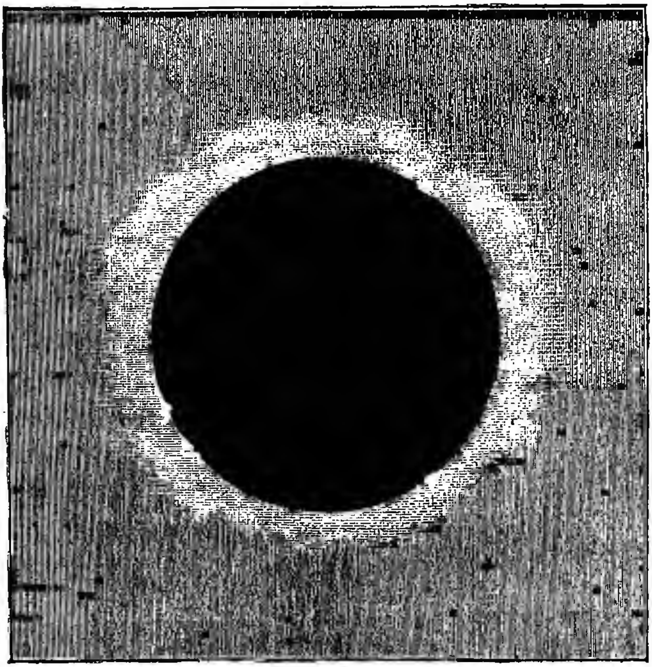

Fig. 48.—The aspect of the Sun in eclipse.

quite prepared to see a certain amount of light around the Sun, but I expected it to be faint and dim, whereas my eyes beheld a splendid aureole, the brilliancy of which, very accentuated upon the edge of the disc, gradually faded away to nothing at a distance about equal to the diameter of the Moon. I had not reckoned upon anything of this kind.

"Mastering my surprise, I again looked through my telescope, having first taken out the black glass inside it.

Here a new surprise awaited me. The corona of rays around the lunar disc was broken at three points by immense purple flames with a diameter of two minutes. They appeared to be perfectly steady, and presented an aspect like the snow-covered summits of the Alps during sunset. I could not discern whether these flames were clouds or mountains, for, while I was studying them, a ray of sun shone through the darkness and prevented me from carrying my examination any further."

VI.

History contains some curious accounts, many of them, no doubt, exaggerated, as to the obscurity which reigns during a total eclipse of the Sun. During that of 1560, the darkness was so intense that people could not see their hand before them. The Agathocles eclipse, which took place in the year 310 B.C., is said to have created so great an obscurity that the stars appeared in every quarter of the sky.

During the eclipse of 1715, Halley saw Venus, Mercury, Capella, and Aldebaran. In another direction, where the atmosphere appeared still darker, he counted twenty-two stars.

During this same eclipse, which took place at 9 A.M., Louville states that it was too dark to read more than a few words here and there.

During most other eclipses, also, observers have been able to distinguish many of the planets and constellations.

It is narrated by eye-witnesses of the eclipse of 1706, that at Montpellier, the bats were flying about, that the fowls and pigeons went to roost, that the caged birds ceased singing and put their heads under their wings, and that the very beasts of burden stopped while at work.

Professor de Lentheric, speaking of the eclipse of 1842 at the same place, says that "the bats, thinking night had set in, left their hiding-places; an owl flew over the town, the swallows disappeared, the fowls went to roost, and some oxen that were passing by St. Maguedelonne church drew up in a circle back to back, as if they were expecting to be attacked."

Abbé Deytal adds that "some horses which were driving a threshing-machine were seen to lie down; the sheep scattered over the meadows flocked together as if in fear; the chickens took refuge under their mother's wing; a pigeon, overtaken in his flight by the obscurity, flew against a wall and, dropping to the ground, did not rise again until the Sun had reappeared."

Arago, alluding to an incident which occurred during the same eclipse, says that an inhabitant of Perpignan, keeping his dog without food on the previous evening, gave him some meat just as the total eclipse was taking place. The animal, which had begun to devour it with great avidity, let it fall from his mouth when the obscurity became complete, and would not touch it until the Sun shone forth again. At La Tour, a town in the Eastern Pyrenees, an inhabitant kept three linnets. Early on the morning of July 8th, 1842, he hung their cage from his window, but though they all seemed in perfect health, one of them died during the eclipse.

Riccioli relates that during the total eclipse in 1415, several birds were seen to drop dead from fright in Bohemia. The same is reported of the eclipse of 1560; and Arago says that during the eclipse of 1842 the fowls which were being fed left the grain and took shelter in a shed, one of the hens covering the chickens under her wing.

It has also been noticed that ants will come to a halt when the Sun is totally obscured, but they do not drop the burdens they are carrying, and continue their journey when the light reappears.

It is also said that some bees which had dispersed from their hive at sunrise, flew back to it at the moment of the total eclipse, and remained there until it was over.

One singular phenomenon, attested by several credible witnesses, is the change which takes place in the colour of terrestrial objects when the obscurity of solar eclipses has reached a certain point. Plantade and Clapés, in their account of the total eclipse at Montpellier on the 12th of May, 1706, relate that objects change in colour according as the eclipse progresses or declines. At the eighth digit, that is to say when two-thirds of the Sun's diameter were hidden by the Moon, both before and after the total obscurity, they were of an orange-yellow tint. When the eclipse had attained rather more than eleven digits, that is to say when only $\frac{1}{25}$ of the Sun's diameter was visible, they seemed to be of the colour of running water.

Halley, speaking of the total eclipse in 1715, says: "When the eclipse had reached ten digits, that is to say when the Moon covered five-sixths of the sun's diameter, the aspect and colour of the sky began to change, the azure blue turning into a sort of livid purple."

These changes of colour, which are merely due to an effect of the law of optics, have been remarked by all succeeding astronomers.

VII.

All lunar and solar eclipses reappear in the same order, after an interval of about 18 years and 11 days, which are termed the *cycle of Meton,* or the *golden number.* The Chaldæans called this period *saros.* Thus, at the expiration of eighteen solar years, the Sun reappears, either in opposition or conjunction, at the same distance from the nodes of the Moon's orbit as it was at the commencement of this period.

It suffices therefore to have observed the eclipses during a period of eighteen years to be able to predict those which will recur during any interval of the same duration.

Roemer, to whose researches we owe the discovery of the velocity of light, invented a sort of planisphere, or watch, which, by the turning of a fly-wheel, indicates all the past and future eclipses of the planets. This and other curious mechanical contrivances are to be seen in the Paris observatory. M. de la Hire also invented a machine which indicates the eclipses past and to come, according to the mean motion of the Moon, together with the points of lunation and the epacts.

The astronomical epacts enable us to predict the eclipses with great exactitude, by calculating the mean conjunctions, or new moons, as well as the mean oppositions, or full moons, then determining for those periods the distance of the Sun from the node of the Moon at those periods, and finally ascertaining if this distance comes within the limits where an eclipse would occur.

As M. Delaunay points out, "the ancients, who had not nearly so precise a knowledge of the Moon's motions as we have, were unable to predict the eclipses of the Sun. They could only foretell those of the Moon, their forecast being based on the periodical recurrence of eclipses presenting the same character, and with the same intervals between them every 18 years 11 days. Thus, after observing and keeping a record of all the lunar eclipses which occurred within that period of time, it was easy to predict the order of the eclipses which would take place in a corresponding period. At the present day, with our extended knowledge of the motions both of the Sun and the Moon, we are able to calculate for years, even centuries beforehand, not only the general circumstances of lunar and solar eclipses, but the peculiarities which they will manifest at any given spot upon the earth. We can even form a retrospective estimate of the appearance presented in different localities by an eclipse that took place hundreds of years ago.* "

Thus eclipses are useful in chronology, either to fix the precise date of a remote occurrence or to correct misleading indications.

Herodotus, in his first book, says: "After that, the Lydians and the Medes were at war for five consecutive years, and the fortunes of the contending armies varied; and while the struggle continued to favour first one side and then the other, it happened that in the sixth year, just as a battle was being fought, the day suddenly changed into night. Thales of Miletus had foretold this phenomenon to the Ionians, indicating the very year during which it actually occurred. The Lydians and Medes, seeing that night had suddenly taken the place of day, ceased their warfare and concluded peace."

This eclipse is known as the *Thales eclipse.* The various authors who have spoken of it assign very various dates,

* Annual report of the *Bureau des Longitudes,* Delaunay, p. 427, 1868.

ranging between 626 and 583 B.C., but Airey, basing his induction upon the most recent data as to the Moon's motions, fixes it on the 28th of May, 585 B.C. Diodorus Siculus also relates some curious details concerning a total eclipse of the Sun which took place whilst Agathocles, flying from Syracuse before the Carthaginians, was on his way to Africa. "Agathocles, though surrounded by the enemy, made an unexpected escape. Upon the following day there occurred so complete an eclipse of the Sun that one might have supposed that night had set in, for the stars appeared all over the heavens. And the soldiers of Agathocles, thinking this presaged the displeasure of the gods, were in great fear." *

Astronomers have ascertained that this eclipse must have occurred in the year 310 B.C.

VIII.

Until astronomy revealed the causes of an eclipse, that phenomenon, like the comets or the Aurora Borealis, was a source of terror to many, and of wonder to all.

One of the most remarkable facts relating to this subject is the use to which Christopher Columbus turned his knowledge of these phenomena at an extremity when he and his fellow-travellers were threatened with starvation. Compelled to have recourse to the natives of the New World for subsistence, he treated them with great kindness. But in the course of time the supply of provisions began to fall short, and the natives exhibited a reluctance to renew them. In this extremity he happened to recollect that a lunar eclipse was at hand, so he assembled all the neighbouring

* Diodorus, Book xx. § 5.

chiefs, informing them that he had an important communication to make concerning the preservation of their life. When they had met, he reproached them with their want of friendliness, assuring them that God, who had him under his protection, would soon punish them. He went on to say: "Have you not seen how I have punished any of my soldiers who have disobeyed me? You will soon be a yet more striking instance of the vengeance wrought by the God of the Spaniards, and as a warning of what is to come, you will this evening see the Moon grow red, and then withdraw its light from you. But this is only the prelude of the misfortunes which will overwhelm you if you refuse to give me food."

The eclipse began a few hours afterwards, and the natives were nearly mad with terror, throwing themselves at Columbus' feet, and imploring pity. He, in order to make his influence over them stronger, pretended to comply with their demand, and retired to an inner chamber, professedly to appease the wrath of the divinity. The natives continued to utter loud cries of alarm, and when the Moon reappeared Columbus told them that the divinity had promised to pardon them on the condition of their supplying him with all he required, and ever afterwards they kept their word.

Fontenelle, in his work *Entretiens sur la Pluralité des Mondes*, says: "Throughout the East Indies it is believed that the eclipses of the Sun and Moon are caused by a dragon with large black claws, which he stretches out to seize those two luminaries, and that is why the Indians are seen plunged up to their necks in water at these periods; for in the Hindoo religion such an attitude is looked upon as favouring the Sun and the Moon in their combat against the dragon. In America it was thought that when the Sun

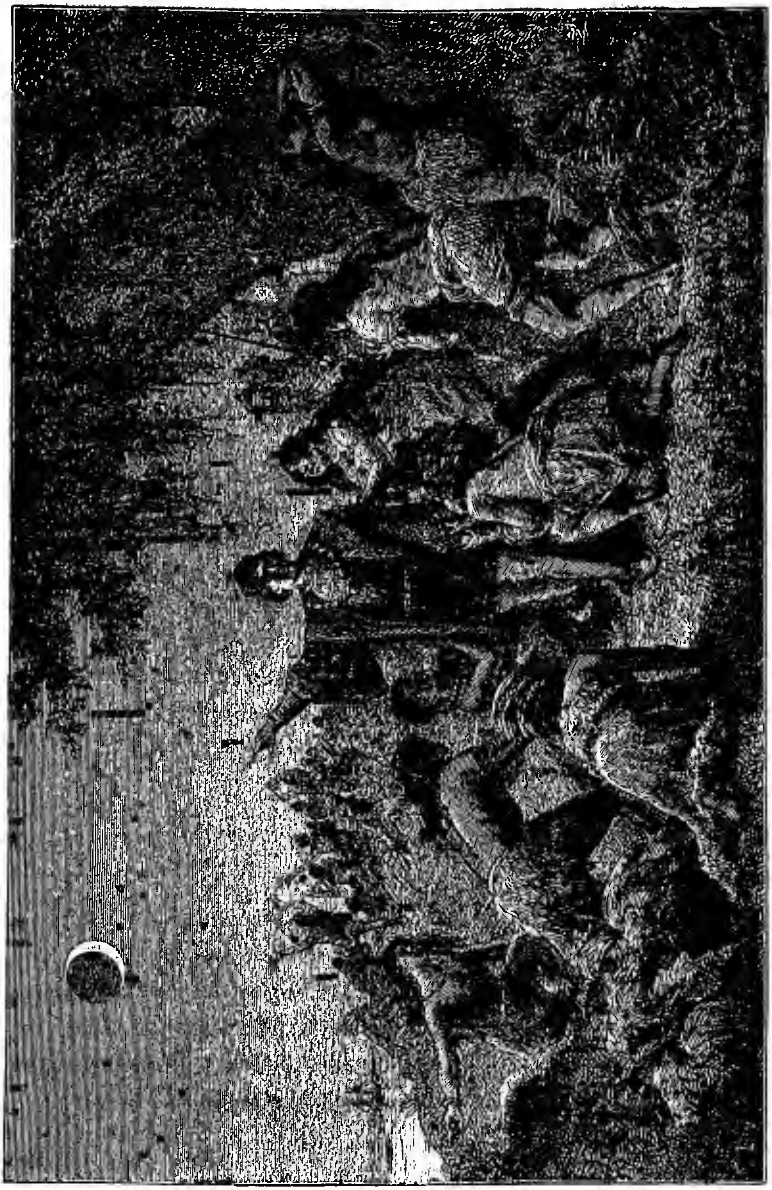

Fig. 49.—Christopher Columbus and the eclipse of the Moon.

and Moon were in eclipse, they were offended, and various devices were resorted to for propitiating them. But the Greeks, civilised as they were, believed that the Moon was bewitched, and that the magicians compelled it to come down from the sky, and deposit a venomous scum upon the grass. And even during the total eclipse of 1654, many people took refuge in their cellars."

IX.

The following fact shows what a great effect eclipses had upon the ancients.

Pelopidas, the Greek general, was about to engage in battle against Alexander of Pheræ (346 B.C.), when "just as all was ready for the general's departure an eclipse of the Sun took place, and the town was plunged in darkness. Pelopidas, finding that this phenomenon had so alarmed his soldiers as to render them incapable of sustaining the combat, started on his expedition, accompanied only by three hundred volunteers, in opposition to the soothsayers and the rest of his fellow-citizens, who looked upon this eclipse as the sign of misfortune to some important personage." *

In the Peloponnesian war, Pelopidas had equipped 150 vessels, and just as all the troops had embarked, and Pericles had taken his place in the trireme, an eclipse of the Sun came on. "The men, alarmed by the sudden obscurity, saw in it a presage of disaster. Pericles, finding that the pilot had lost all control over himself and his vessel, threw his mantle over his head, and asked him whether he saw anything alarming in that. The pilot replying in the negative, Pericles told him that the only difference between

* Plutarch's *Life of Pelopidas.*

the causes of obscurity was that the Sun was larger than his mantle." *

Drusus, sent by Tiberius to quell the revolt amongst the Roman legions, took advantage of the terror inspired by a lunar eclipse to restore order. Tacitus, referring to this occurrence, says: "Matters looked very threatening that night, but a happy accident re-established order. The Moon, which was shining in a clear sky, suddenly grew dim. The soldiers, unacquainted with the cause of this phenomenon, imagined it to have some bearing upon their own position, thinking that the eclipse of the Moon was meant to represent their own sufferings, and that if it regained its normal brilliancy, they would attain the object of their desires. Then they began to sound their clarions and trumpets, their spirits being elevated or depressed according as the Moon became brighter or more obscure; and when the mass of clouds at last concealed it from their eyes, they thought that it had disappeared for ever, and, as the transition from terror to superstition is an easy one, they inferred that the gods were angry with them for rebelling." † Tacitus then goes on to describe how Drusus took advantage of their fears.

The appended story, somewhat analogous to that of Christopher Columbus, described above, will also serve to show the light in which two ancient nations envisaged these phenomena.

Plutarch, in his *Life of Paulus Emilius*, says that on the eve of a great battle with the Lacedæmonians, "the Moon, which was shining brightly in the sky, suddenly began to grow dim, and, after undergoing several variations of

* Plutarch's *Life of Pericles.*

† *The Annals* of Tacitus, book i.

colour, became altogether eclipsed. The Roman soldiers began to beat upon the brazen vessels, as is their habit on such occasions, in order to call back the light, elevating, at the same time, torches and firebrands towards the sky. The Lacedæmonians, on the contrary, were struck with terror, and a loud cry went through their camp that the phenomenon heralded the downfall of their king. Paulus Emilius, though he was not altogether unacquainted with the natural causes of an eclipse, obedient to the customs of his religion, sacrificed eleven young bulls when the Moon shone forth again. At daybreak he immolated twenty oxen to Hercules, without, however, obtaining any propitious signs; but when the twenty-first ox was slain, the signs appeared, announcing that he would be victorious if he remained on the defensive."

X.

Nicias, the Athenian general, and his soldiers, alarmed by an eclipse of the Moon, were surprised by the Syracusans in Sicily, his army defeated, and himself taken prisoner and put to death.

Plutarch, in his *Life of Nicias*, pens the following remarkable passage: "Anaxagoras, who was the first to write an account of the phases of light and shadow observed in the Moon, was not at the time a well-known author, and his treatise, far from being generally circulated, was kept a profound secret, and only confided to a very few persons, who did not place much reliance upon its contents. Moreover, natural philosophers, and *meteorolesci*, as they were then called, were held in great abhorrence, for it was said that they degraded the divinities by reducing their influence to capricious causes, unregulated forces, and necessary passions. Thus it was that Protagoras was exiled, Anaxagoras cast into prison, and with difficulty saved from death by Pericles; and Socrates, though he had nothing in common with their doctrines, put to death because he was a philosopher. It was not until much later that the doctrines of Plato enlightened his fellow-citizens, and, aided by the life of its expounder, as by his submission to the physical causes involved in the principles of divinity and sovereignty, put an end to the calumnies which were heaped on philosophy. His doctrines, too, brought about the study of mathematics. This is the reason why his friend Dion, who noticed an eclipse of the Moon just as he was about to start from Zacynthus to attack Dionysius, was not deterred from setting sail, and continued his voyage to Syracuse."

It is very evident that the more the works of nature are studied, the greater must be our admiration of the wisdom of their Creator. The Almighty has effected his purpose with the most simple means, as we see the more clearly the further we advance in science, the study of which, so far from having a tendency towards impiety, must rather animate us with the sentiments of Plutarch, who, though he had no conception of the great physical and moral truths now within human ken, exclaims:

"Man enlightened by the study of Nature's laws cannot but be inspired towards the Divinity with a feeling of veneration, full of security and hope, instead of a superstitious and timid devotion." *

* Plutarch's *Life of Pericles*, p. 267.

CHAPTER X.

THE TIDES.

Their nature—The first of the Greeks who inquired into the causes of this phenomenon—Passage from Lucanus—Influence of the Moon and the Sun upon the waters—Theory of tides—M. Delaunay on the tides—Solar and lunar tides—Obstacles to tides—Height of tides in the Moon—Flood-bar or "bore"—M. Babinet's description—Utility of tides—A charming allegory.

I.

TIDE (marée) is derived from the Latin *mare* (sea). It is the alternating and daily motion of the ocean covering and receding from the shore. In the course of 24 hours 49 minutes its waters twice flow to and recede from the equator towards the poles, and from the poles towards the equator.

The sea rises for about six hours, covering the shore, and forcing its way up the mouth of the rivers. The waters, after attaining their extreme height, remain a short time (about a quarter of an hour) unchanged, and then gradually recede. This retreating motion also lasts about six hours, when they reach their lowest depression, when, after a quarter of an hour's repose, they again begin to rise.

The *flood*, which is also called *high tide*, is the motion of the waters towards the poles; the *ebb*, also called *low tide*, is the return of the waters towards the equator.

II.

The first of the Greeks who directed attention to the causes of the tide was Pytheas of Marseilles, who lived about 320 B.C. He asserted that the full Moon produced the flood, and the waning Moon the ebb; but, though it is true that tides are attributable to lunar influence, he was very far from the truth. Newton first demonstrated the relation of tides to the other phenomena of universal gravity.

Lucanus, alluding in the *Pharsalia* to the French coasts, thus speaks of the tidal phenomena:—"There is the same gladness upon this shore, for the possession of which earth and water seem to be disputing, as it is in turn abandoned and inundated by the ocean. Is it the ocean itself which rolls its waves from the extremity of the axis, and then draws them back to it? Is it the periodical return of the luminary of night which drives them before it? Is it the Sun which attracts them to feed its flames, which, pumping up the sea, raises it towards the sky? Let those who seek to study the working of creation sound this mystery. For my part, as the gods have concealed from me the mighty cause of this great motion, I do not seek to fathom it."*

Newton and Laplace, to use M. Babinet's expression, *sought*, and, to the great honour of the human race, *found*. As the Moon successively passes above each point of the ocean, it, by virtue of the laws of attraction, draws towards it the waters, which are of extreme mobility.

III.

It has been ascertained:—

1st. That the waters of the ocean rise in succession at each point over which the Moon passes;

2nd. That the Mediterranean has no other tide than that

* Lucanus, *The Pharsalia*, book ii.

imparted to it by the ocean through the Straits of Gibraltar, the reason being that the Moon never passes over it perpendicularly;

3rd. That the ebb and flood undergo, like the Moon, a retardation of three-quarters of an hour every day;

4th. That the tides only recur at the same hour once in every thirty days, which is precisely the interval between two new moons;

5th. That the tides are always highest when the Moon is at its nearest point to the Earth;

6th. That the tides are highest at the time of full and new moon, because at that time the waters are more strongly attracted, owing to the attraction of the Sun being concurrent with that of the Moon; whereas at the epoch of the quadratures and quarters the tides are less, because the Sun neutralises about a third of the Moon's attraction.

IV.

When the Moon is perpendicular over a particular point of the ocean, the waters there, attracted by the orb of night, begin to rise, and, as this attraction acts in a contrary direction to that of the Earth, the waters upon each side of the globe, exposed to an oblique action from the Moon, augment in weight, and tend more towards the centre of the Earth. At the same time, those parts of the sea diametrically opposed to the point attracted by the Moon, being less attracted by that luminary than the centre of the Earth, because they are farther away, do not tend so much towards the Moon as the centre of the Earth, by which means the sea rises on the side opposed to the Moon, and the ocean presents the phenomenon of tides in two opposite hemispheres.

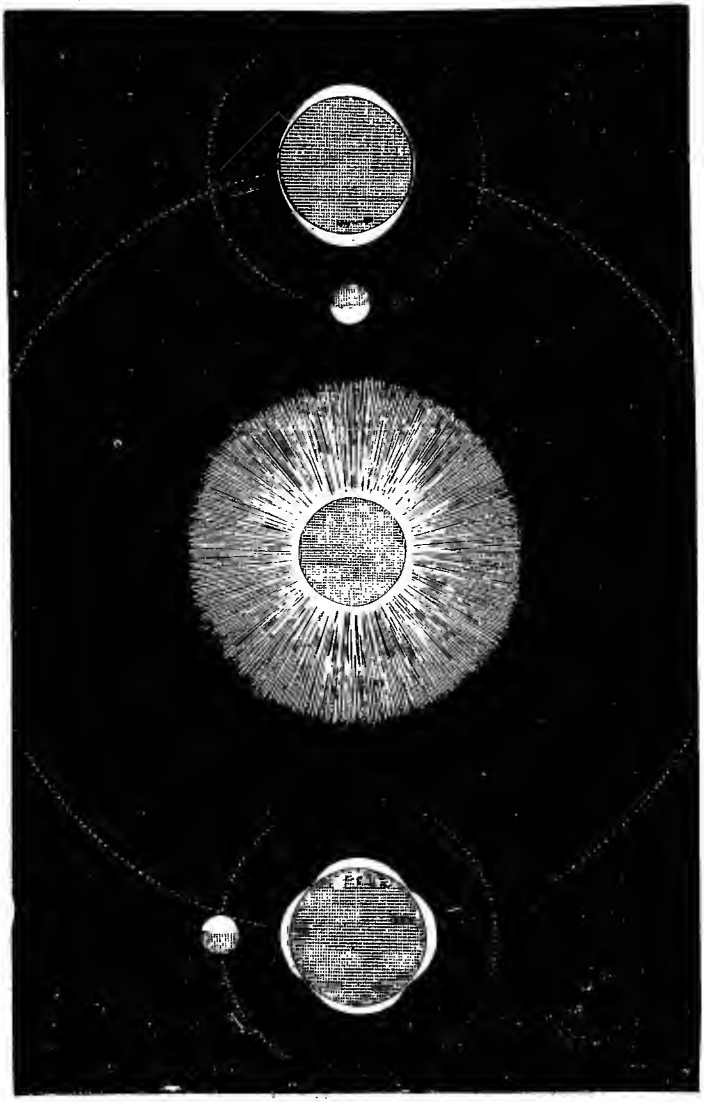

Fig. 50.—The phenomena of tides.

The attractive force exercised by the Sun upon the Earth, though only a third of that of the Moon, suffices to cause an ebb and flow.

Thus there may be said to be two separate sorts of tide: the solar and the lunar.

The Sun causes a rise in the sea at noon and midnight, the hours of its passage across the meridian, and produces a fall at ten in the morning and ten in the evening.

Twice a month, at the *syzigies*, these two tides concur in direction, and combine into one, because at that time the Sun attracts the waters in the same direction as the Moon, and produces a corresponding effect; whereas at the quadratures, as I have already said, the Sun, being perpendicular to the Moon, has an action contrary to that of the latter. Hence it is that the tides are least during the first and last quarters, greatest at the full and new Moon.

V.

M. Delaunay writes as follows concerning the theory of tides:

"If the Earth was altogether a solid body, it would give as a whole under the attraction which the Moon exercises upon its various parts, without undergoing the least alteration in shape. But the Earth is not altogether solid. Part of its surface is covered by the waters of the ocean, which, by reason of their fluidity, are easily moved by the forces which act directly upon them. Now, the various portions of these waters, spreading all around the terrestrial globe, and, consequently, placed at unequal distances from the Moon, are not equally attracted by it. In that region of the globe's surface which is turned towards the Moon, the waters of the sea are more powerfully attracted than the solid portion of the Earth, taking it as a whole; in the opposite region, on the other hand, the sea waters are less attracted than the solid part. It results from this that the waters situated on the side facing the Moon are made to tend towards it by this excess of attraction, and that on the opposite side of the Earth the waters tend to recede relatively to the mass of the globe which is more strongly attracted than they are. The consequence is, that the waters accumulate together on the side where the Moon appears, forming a prominence there which would not exist but for it, while just in the same way they accumulate and form a prominence upon the side opposed to the Moon. Added to this, the Earth, by virtue of its rotatory motion upon itself, brings the various parts of its surface perpendicular to the Moon, so that the two liquid prominences in question, while always occupying the same position in respect to the Moon, are continually changing their place upon the surface of the Earth; and it will be found that at the same point on this surface, in the same part, two high tides will be observed in succession—and consequently two low tides—while the Earth is making a total revolution relatively to the Moon, that is to say, in the course of 24 hours 49 minutes.

"The Sun produces an analogous effect upon the waters of the sea, but the enormous mass of the solar body is more than counteracted by its great distance from the Earth; so that, as a matter of fact, the tide caused by the action of the Sun is not comparable to that due to the action of the Moon. The phenomenon, therefore, in its main features, is dependent upon the position of the Moon in respect to the Earth; the action of the Sun merely modifies it, either by advancing or retarding the hour of high-tide, either by augmenting or diminishing its intensity, according to the position which the Sun occupies in the sky as regards the Moon."*

VI.

The highest point of the tide is never exactly underneath the Moon, but a short distance, at no time exceeding 15 degrees, to the eastward.

The waters of the ocean, being very inert, do not yield immediately to the attraction which the Moon exercises upon them, and this is why they do not attain their highest elevation at the moment when the lunar attraction is greatest, but a short time afterwards.

Not only does the solar attraction impede that of the Moon, but the resistance and oscillation of the waters, the friction of the coasts, and their irregular shape, are all so many obstacles which retard the high tide. At the Cape of Good Hope, for instance, there is a retardation of two hours and a half, but at Dunkirk and Dover it is twelve hours, that time being taken by the ocean to traverse the English Channel and the Straits of Dover, and to force itself along the coasts. But the flood and the ebb are, notwithstanding, quite regular in their recurrence.

VII.

The maximum and minimum of elevation in the ocean depends not only upon attraction, but also upon the bed of the sea and the coast-line. It is easy to understand that

* Delaunay's *Annuary* for 1868, p. 467.

the tide will be higher in a narrow channel, where the waters are forced together, than upon a wide and open shore. At St. Malo, in the English Channel, the tides are sometimes 50 or 60 feet; in the north of the Bay of Biscay, and at Brest, they rarely exceed 23 or 28 feet; at St. Helena they are never more than four feet. At the Island of Roumon, and other points of the great Southern Ocean, the height of the tides is but 18 inches.

It has been noticed that at the mouth of the Garonne, the flood lasts seven hours, and the ebb only five, and this difference is attributed to the course of the stream, the current of which runs down in a contrary direction to the flood, and consequently quickens the ebb.

The wind has also a certain influence upon this phenomenon. If it is blowing strongly in the direction of the tide, the waters rise higher than during calm weather; but if the wind is blowing in the opposite direction, the tide is lower.

The tide varies in height from day to day, even upon the same coast. It augments for a week, and then diminishes during the same lapse of time, so that, twice in every month, there are two high tides at an interval of a fortnight, and two low tides at the same interval; while twice a year, at the spring and autumn equinoxes, there are two tides much higher than at any other period.

Newton calculated that if there are seas in the Moon, the attraction of the Earth must cause the tides there to be more than 100 feet high, whereas the general average of the Moon's attraction does not raise the waters of our globe to a height of more than 15 feet.

VIII.

The coasts and the basin of the Seine present a curious tidal feature near Quillebœuf; it is termed, during the full and new Moons of the equinoxes, the *flood-bar*, or "bore," and has been well described by the late M. Babinet, who says:

"This extraordinary motion of the sea-waters, immense in its development, and capricious in its action, owing to the influence of localities, winds, and the variable state of the bed of the stream, has formed the subject of long researches, the result of which I now lay before you. The first point to be considered is the meaning of the word. Whereas, as a general rule, and even at the extreme mouth of the Seine itself, as at Le Havre, Honfleur, and Berville, the sea, at the commencement of the flood, rises gradually and almost imperceptibly, in that part of the stream above and below Quillebœuf it precipitates itself in an immense cataract, forming a sort of rolling wave, which extends right across the river to a distance of six or seven miles, and instantaneously fills the vast basin of the Seine.

"This great wave, after dashing itself against the quays of Quillebœuf, runs up the narrow bed of the stream, which at that point remounts towards its source faster than a race-horse can gallop. The vessels, drifted about, are, to use a local expression, *en perdition*. The bed of the stream undergoes a displacement of several miles from the one to the other of the cliffs, which overhang it, and the sand and mud banks in the bottom are agitated like the waves upon the surface. Nothing can be more remarkable than these 'bores,' seen on a calm and bright day, without any such apparent cause as wind or thunderstorm.

"These great crises of Nature, brought about by that eminently silent cause *universal attraction*, are announced and accompanied by the most deafening noises. Homer, the great painter of Nature, would seem to have witnessed some such phenomena when he says: 'So at the mouths of a river whose course is directed by Jupiter, the immense wave roars against the current, while the precipitous shores re-echo afar the noise of the sea, which the river is repelling from its bed.'"

IX.

A great advantage of the flood-tide is that it forces the sea-water up the rivers, and makes their beds deep enough to admit ships of heavy tonnage. The tides also prevent the sea, which is the receptacle for a vast quantity of filth, from becoming stagnant, which would infallibly happen unless the perpetual oscillation of the tides purified its waters, by propagating in all directions the salt which the sea produces, and destroyed the putrefying matters that would otherwise prove noxious to us.

Fig. 51.—Rhea (from the design of a Roman lamp).

CHAPTER XI.

THE PLANET MARS.

Recent observations of the planet Mars—Its close analogies with the Earth—Its reddish aspect—Its atmosphere — Its soil—Its different names—Curious mistakes to which the distances of Mars from the Earth may give rise—The seasons in Mars—Its poles of ice and snow—Its forests, seas, and islands—Dimensions, translation, rotation, and phases of Mars.

I.

THE planet Mars is our neighbour in space, and presents such close analogy with our globe, both in respect to atmospheric phenomena and polar cold, that anything appertaining to it is specially interesting.

To the naked eye Mars does not appear to be very brilliant. To judge by its reddish hue, it must be surrounded by a very dense atmosphere, greater than that of the Earth, a theory which is confirmed by the fact that the stars by which it passes disappear completely before the globe of Mars eclipses them.

M. Arago says that its light is at times scintillating; but some astronomers have attributed its reddish hue to the constitution of its soil.

Sir John Herschel remarks that, "in this planet we can very plainly discern the outlines of what may be considered as continents and seas. The continents are distinguishable by that reddish colour characteristic of the light of this planet, which seems to be perpetually in flames, and which indicates beyond doubt that the soil is mostly ochre-coloured, just as the quarries of red sand in certain parts of our globe may seem to the inhabitants of Mars. The only difference is that the tint is of a more pronounced shade, owing to a contrast, which is attributable to the laws of optics. The seas, as we may call them, appear to be of a greenish hue."

It is because of this reddish colour that in Hebrew the name Mars signified *ignited;* with the Greeks, Mars, also called Hercules, generally took the epithet of *incandescent;* and the Indians called it *Angaraka,* which signifies *burning coal,* and *the red body.*

II.

None of the planets can compare with Mars for its excessive variations in brilliancy, which are due to the fact that its distances from the Earth and the Sun undergo great changes, according to its position in the sky.

Its ellipse is very eccentric: at the period of conjunction it is about 245,249,000 miles from us; at the period of opposition, only 62,389,000 miles. These very unequal distances from the Earth lead to great variations in its apparent disc. Thus, in the month of March, 1719, Mars, being in opposition and also at its least distance from the Sun, emitted so brilliant a light that many persons took it for a newly discovered star, while those not versed in astronomy were alarmed at its abnormal appearance. Its ellipse varies but slightly from the plane of the ecliptic, forming only an angle of 1° 51′.

The Sun is in the northern hemisphere during the half-duration of the planet's revolution, and afterwards in the opposite hemisphere. Thus, these two periods are separated by equinoxes similar to those of the Earth, and for the same reason Mars has seasons analogous to those of our globe. This explains a singular phenomenon which has been observed near the north and south poles of Mars; viz., the growth and decline of two white spots, the brilliancy of which is double that of any other part of its surface.

The northern spot diminishes in size during the spring and summer of the northern hemisphere, and augments during the two following seasons, the process being reversed in the south pole. This indicates a successive formation around the poles in Mars, of large caps of snow and ice which increase and diminish in size according to the temperature.

Upon our globe the northern hemisphere comprises the largest tracts of *terra firma*, but in Mars the reverse seems to be the case, for it is only at the 60th degree of lat. S. that the mainland in this planet begins, extending from the north to the equator.

III.

The most favourable opportunity for studying the aspect of Mars occurs when it is in opposition with the Sun, as then it crosses the meridian at midnight, and is nearer to the Earth than at any other period.

When Mars was in opposition during the month of April, 1856, Father Secchi distinctly recognised the two snowy spots of the polar regions, and he ascertained that their centres did not coincide with the poles of rotation. These two spots rapidly diminished in size when they became exposed to the solar rays, but they increased both in extent and brilliancy as they moved away from the direct radiation of the Sun.

The dark spots of various shapes which are visible through a glass upon the disc of this planet are, on the contrary, fixed bodies, which seem to form part of its surface; but they vary in aspect just as our forests might do when seen at different seasons and divergent latitudes.

During the summer of 1858, Father Secchi took advantage of the opposition of Mars in the month of May, to take a series of minute drawings of that planet, which the use of the great equatorial (a telescopic instrument) at the College of Rome enabled him to do. The colours of the spots seem to vary much, some being red, others blue, green, or white. The opposition of 1862 was taken advantage of by many English astronomers. Messrs. Grow and Joyson sent sketches of the planet to the Astronomical Society of London, and Professor Phillips, of Oxford, presented *The Royal Society* with a series of drawings obtained by combining his own observations with those of other astronomers, which were intended to show the phenomena presented by Mars during the whole period of its relative proximity to the Earth.

It was in such a position that the whole circle of snow which surrounds the south pole was distinctly visible, and its outlines were so clearly defined that the observers were enabled to remark that it terminated in a steep declivity.

The snows of the northern hemisphere are but dimly visible, and every thing tends to show that the white caps are not all situated in the same hemisphere, if we may so speak, of the planet.

The equatorial region is occupied by a large green belt, with deep bays and receding inlets, which seem to indicate

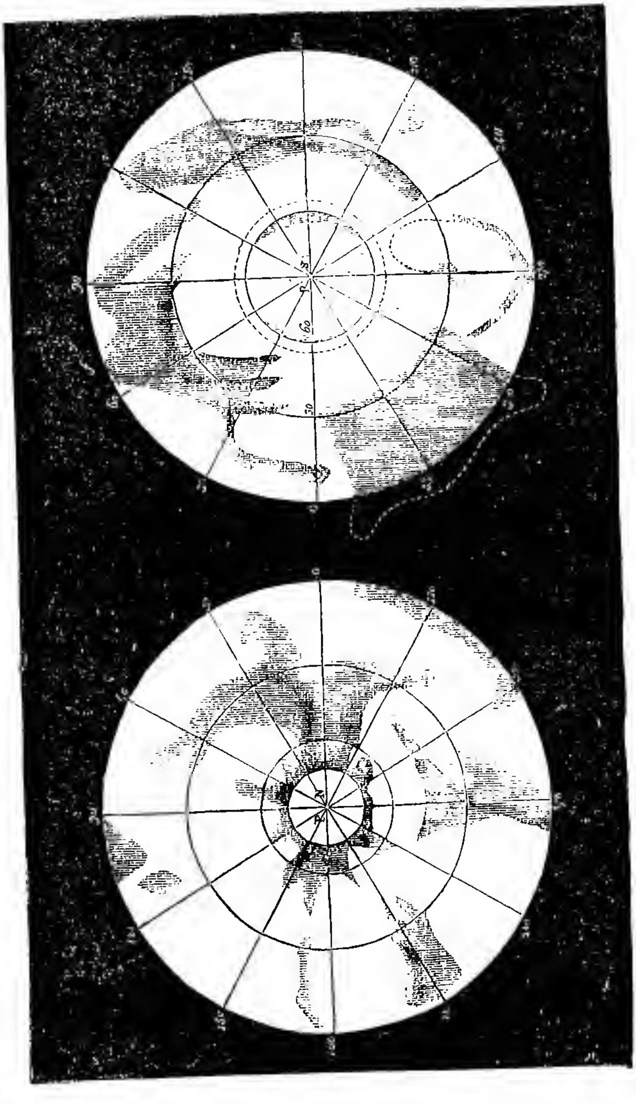

Fig. 52.—Map of the planet Mars (after Maedler).

that this part of the planet is a mass of water. At one point in this region rises an island, which has the same reddish hue as the two great continents above and below the equatorial band.

M. Vinot says, that "a very clear idea of the ordinary appearance of Mars may be obtained by studying the map of North America. Supposing the ocean which surrounds America to be *terra firma*, and America itself an ocean, we get a very close likeness of what the astronomers term, in Mars, the *Ocean de la Rue*." *

M. Stanislaus Meunier sees a proof of the great age of Mars in the shape of its seas. It seems clear to his mind that the seas on our globe will gradually assume the same outlines as those of Mars when they have undergone a certain diminution of volume, consequent upon their progressive absorption by the solid nucleus.†

M. Flammarion, in an interesting paper upon Mars, gives the following compendious account of the facts which seem to be placed beyond the possibility of doubt in regard to this planet: 1st, the polar regions are alternately covered with snow, according to the seasons and the variations due to the great eccentricity of its orbit, the ice of the north pole not at present extending beyond the 80th degree of latitude; 2nd, clouds and atmospheric currents exist there as upon the Earth, the atmosphere being more charged in winter than in summer; 3rd, the geographical surface of Mars is more equally divided than that of our planet into continents and seas, the latter slightly predominating; 4th, the meteorology of Mars is almost the same as that of the Earth, the water having the same physical and chemical

* Vinot's *Bulletin Astronomique* for 1873.

† *Académie des Sciences* (September 1st, 1873).

properties; 5th, the continents seem to be covered with a reddish vegetation; 6th, the force of analogy shows us that this planet possesses, *in a greater degree than any other*, organic conditions in close affinity with those of the Earth.*

IV.

The apparent diameter of Mars varies from 18″ to 4″; its real diameter is 4,000 miles, its surface is only a third that of the Earth, and its volume one fifth; its mass is but a tenth that of our globe, and its weight scarcely half.

It receives only $\frac{4}{9}$ths of the heat and light which the Earth receives from the Sun, and the latter luminary must appear only a third the size it does to us.

Its mean distance from the Sun is 139,312,000 miles; its revolution is accomplished in 686 days, 23 hours, 30 minutes, 41 seconds, which is almost double that of the Earth. Its rotation takes 24 hours, 30 minutes, 21 seconds.

Mars is the only superior planet in which we can distinguish phases; the obscured portion of its disc never exceeds an eighth of its total surface. At the epoch of its quadratures it presents a more or less elongated oval shape, but never that of a crescent.

Galileo, writing to Father Caselli on the 30th of December, 1610, says: "Without positively asserting that I have distinguished the phases of Mars, I am almost certain that this planet is not quite round."

Ricasoli says that, on the 24th of August, 1638, Fontana,

* *Académie des Sciences* (July 28th, 1873).

of Naples, distinctly observed the absolute gibbousness of Mars. This observation, at the time it was made, was unquestionably a discovery of importance, but in the present day the merest tyro in astronomy, who is in possession of a good glass, can easily perceive the phases of Mars at the epoch of the quadratures.

CHAPTER XII.

JUPITER, SATURN, URANUS, NEPTUNE.

Jupiter—Its distance from the Sun—Its motions—Aspect of its surface—Its dimensions—Its satellites—Their eclipses and the velocity of light—Saturn—Its distance from the Earth and from the Sun—Saturn's ring—Nature of this ring—Its aspect—Its dimensions—Various hypotheses—Uranus—Its motions—Its dimensions—Its satellites—Neptune—Its distance from the Sun—Its rotatory motion round the Sun—Its perturbations.

I.

Jupiter.—Jupiter is distant 475,693,000 miles from the Sun. In the space of 11 years, 307 days, 14 hours, 18 minutes, 9 seconds, it travels over an orbit of more than two and a half milliards of miles round the Sun, consequently travelling at a rate of 25,000 miles an hour.

The motion of this planet upon itself is much more rapid than that of the Earth, taking place in 9 hours 56 minutes.

The displacement of the spots which the telescope has discovered upon its disc, prove to us that Jupiter revolves upon itself. Nearly all of these spots have the shape of longitudinal bands, some of them obscure, and others luminous.

Their number varies very much, and sometimes they all appear to be adherent, like long zones which envelop the planet, while at other epochs there is a solution of continuity. While at one time only one or two are visible, at another seven or eight can be seen.

At various intervals, too, certain very salient points become visible, which denote still more precisely the daily motion of this planet upon its axis. Some astronomers consider these different spots to be seas dotted with islands, and extending over the globe of Jupiter in the direction of its rotary motion. Others, again, look upon the obscure sections as constituting the body of the planet, and the luminous sections as clouds driven by the wind in various directions, and at varying speed.

M. Tacchini has communicated to the Académie des Sciences (February 17th, 1873) the result of the observa-

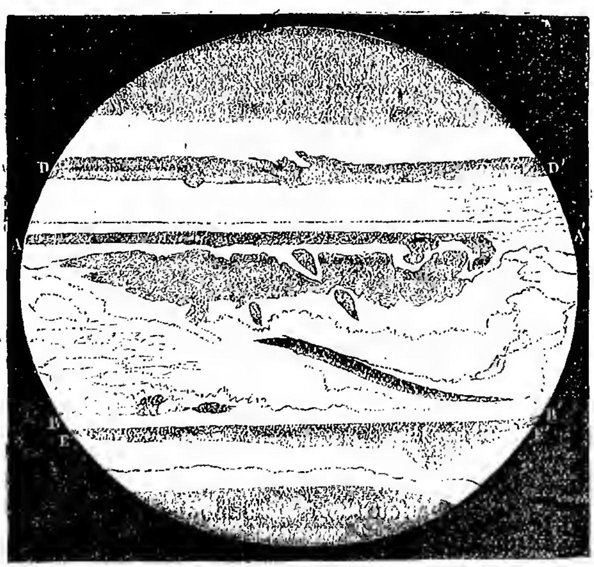

Fig. 53.—The planet Jupiter, as seen by Tacchini, at Palermo, on the night of January 28th, 1873.

tions of Jupiter which he made at Palermo, in January, 1873, accompanied by an engraving (see Fig. 53) representing the aspect of that planet on the night of January 28th. He states that it is not traversed by numerous bands, regular in shape, but that the surface is subdivided into clearly-defined zones, the most irregular of which is that comprised within the parallels AA′ and BB′. The white parts of this zone were bright, like silver; there were also some black spots surrounded by the same white substance, and they resembled small solar spots with very pronounced faculæ. Near the edge, between the obscure lines, DD′ and EE′, the surface appeared to be covered with whitish clouds, and the two polar caps were of a slightly ashen tint. M. Tacchini adds:—"Comparing the present drawing and that executed in 1872 with those taken in 1867 and 1871, it is evident that Jupiter is in a period of variability."

The least distance of Jupiter from the Earth, 408,709,000 miles, is too great to admit of our distinguishing its phases. Its diameter is 85,399 miles, which makes it 1,387 times larger than our globe.

As Jupiter is five times further from the Sun than the Earth, the orb of day must seem only a fifth the size it does to us, and transmit but a twenty-fifth part of the light and heat which we receive.

But this deficiency may be partially compensated for by the fact that its nights only last five hours, and that it possesses four satellites or moons like ours, one of which at least is always visible throughout these brief nights.

The first and the fourth of these moons are as voluminous as Mercury. The second and the third are of about the same dimensions as our satellite. The fourth seems specially destined, by reason of the inclination of its orbit to the equator, to give light to the poles in Jupiter.

All of these satellites revolve round Jupiter in the direction of west to east, and further resemble our Moon in that they always present the same face, owing to the fact of their only making a single turn upon their axis, though still accomplishing their complete revolution round the planet. This has been concluded from the periodical return of the spots observed upon their surface.

The *first* satellite is that nearest to Jupiter, the *second* is the one next nearest, and so on.

The three nearest undergo an eclipse at each revolution, but the fourth, owing to the inclination of its orbit, only falls within the shadow of Jupiter four years out of six. These eclipses can be calculated beforehand, like those of our Moon.

It was by means of these eclipses that Roemer, the Danish astronomer, succeeded in determining the velocity of light, having observed that they always occurred about 16′ 36″ later when Jupiter was in conjunction with the Sun upon the other side of the ecliptic, than when it was upon our side, in opposition. Whence he concluded that light took that time to traverse the whole diameter of the terrestrial orbit; that is to say, about 182,000,000 miles.

II.

Saturn.—Saturn's mean distance from the Earth is 922,640,500 miles, and, owing to its enormous distance, it transmits to us a very faint light of a leaden hue.

Though 746 times larger than our globe, it only appears to us the size of a star of the second magnitude. It is about 872,135,000 miles from the Sun, and takes 29½ years to travel over an orbit of nearly five milliards of miles round the Sun, at a velocity of 21,000 miles an hour.

Seen from Saturn, the Sun must seem ninety times smaller than from our globe, and consequently transmit to it a very trifling amount of light and heat. But, in addition to eight moons which revolve around it, and give it their light, Saturn is surrounded by two flat rings, wide and shallow, both of which have the same centre as the planet. They both repose in the same plane, being separated from each other all along their circumference by a very slight interspace, but they are farther removed from the planet itself.

It would be difficult to make any positive statement as to the nature of this double ring, but it appears to be analogous to the planet itself, for it projects a very intense shadow over it; and whenever the Sun and the Earth are upon the side of this plane, the ring is luminous, whereas when it occupies an intermediate position in respect to the Earth and the Sun, that part which is turned towards us, no longer receiving the solar rays, becomes altogether invisible. This is a proof of its opaqueness, and that its brilliancy or obscurity in relation to the Earth depend upon the various positions that Saturn occupies in its orbit.

It has also been remarked that, soon after its period of brilliancy, the ring gradually contracts, owing to the displacement of the planet in space, and eventually appears only as a thin luminous line, which finally vanishes.

After a certain lapse of time the ring reappears, gradually grows larger, and, swelling out to its greatest breadth, enables us to discern, in the interspace which separates it from the planet, a part of the sky with the stars shining in it.

This interspace is, according to Herschel, not less than 37,570 miles, the ring itself being 27,610 miles in breadth.

It is divided into two distinct annuli, separated from each other by an always obscure space of 1,680 miles.

The inner ring, that nearest to Saturn, is 17,605 miles in breadth; it is surrounded by the second, which is only 9,625 miles in breadth. The edges are not flat, but spherical or rounded, and their base, which is about 90 miles, seems to be dotted with several high mountains.

As this double ring has an inclination of 31° 35′ towards the plane of the ecliptic, we never see it except obliquely, in the shape of an ellipse, the maximum width being about half its length.

Mr. Hirne, a corresponding member of the French Institute, deeming that the modern theories of thermodynamics, which are partly based upon his own researches, might be applied to celestial mechanics, commenced to investigate this subject, and compiled a memoir upon the rings of Saturn, which M. Faye read before the Académie des Sciences (September 16th, 1872).

It is difficult to determine the nature of this double ring. It has hitherto been considered analogous in character to the planet itself, but Hirne, on the contrary, argues that the rings of Saturn are not *solid*, circulating around the planet in the plane of its equator, and *ballasted* at certain points by a slight surplus of matter, so as to impart solidity to their remarkable equilibrium; that they are not, again, fluid or liquid rings, in which the mutual reactions of the molecules tend inevitably to transform active force into heat, which would be lost in space, but that they are simply aggregations of disconnected matter, the parcels of which are very widely separated from each other in proportion to their dimensions. He goes on to demonstrate that this theory coincides with Laplace's idea as to the origin and

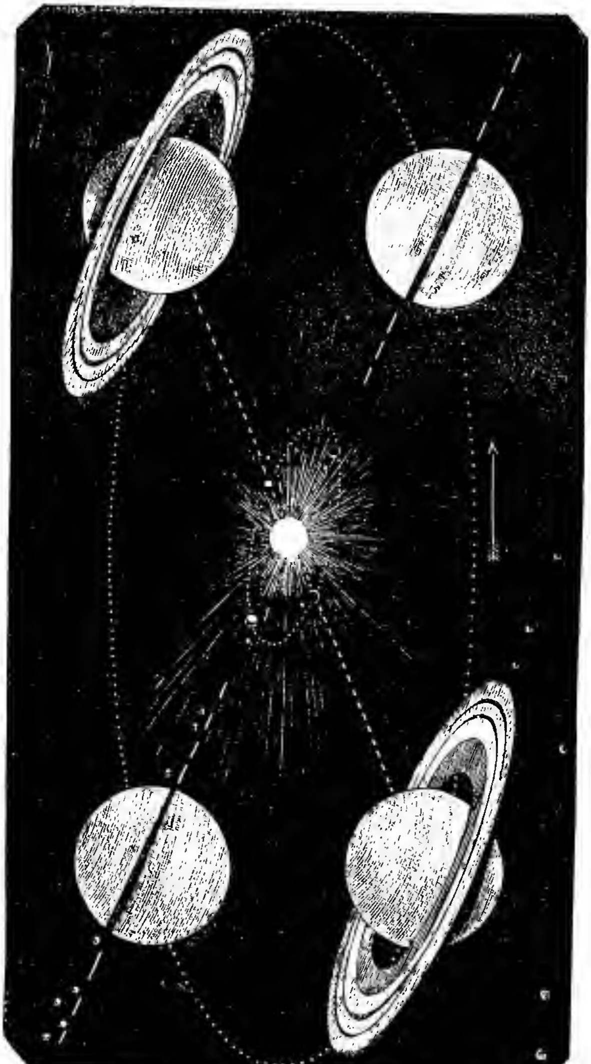

Fig. 54.—Principal phases of Saturn as seen from the Earth.

formation of these singular appendages, but that the condensation caused by refrigeration must have produced an infinity of distinct corpuscles, uniformly distributed in the primitive rings, instead of gradually uniting them in isolated masses like the satellites, or grouping them into continuous solid and coherent rings, the formation and deportment of which do not seem compatible with our actual notions about physics. M. Faye adds, that astronomers, in their study of the black shadow projected by the rings upon the planet have also thought that they must be opaque and solid; but that at the epoch of the last disappearance, in 1848 and 1849, it was remarked that this opacity was by no means absolute, for when the plane of the ring passed between the Earth and the Sun the ring remained visible through powerful instruments, on the side that was not in receipt of light. It is true that astronomers have endeavoured to reconcile this phenomenon with the hypothesis of solid and opaque rings, by the introduction of a fresh hypothesis, which consists in attributing to the rings an atmosphere of their own, capable of producing upon the non-lighted face a faint crepuscular light. But, upon reading Hirne's paper, M. Faye thinks it is far more probable that the rings admit the passage of a few beams of light through the interstices of their discontinuous elements.

During the discussion on this paper, M. A. Guillemin quoted a well-known passage from the *Elements of Astronomy*, by Cassini II., to the effect that the rings are beyond doubt an aggregation of satellites, all of them situated in nearly the same plan.* M. Volpicelli mentioned the fact that Bressel, speaking of the eccentricity of Saturn's ring, argued that it was only to be explained on the hypothesis that this ring

* *Académie des Sciences* (September 23rd, 1872).

has no rotary motion, or that it consists of a large number of parcels capable of independent motion. Moreover, in the vocabulary of Marbach, we read:—"As to the nature of Saturn's ring, it seems from probable analogy that this ring consists of an accumulation of satellites, completely filling its orbit. It may be that these satellites are not in contact with each other, but Saturn is too far removed from the Earth to admit of our ascertaining the distance which separates them."*

Hirne's assertion that the particles forming the ring are separated by very large intervals of space seems scarcely reconcilable with the fact of the ring projecting a shadow upon the surface of Saturn (Académie des Sciences, October 21st, 1872).

Of the eight satellites of Saturn, four were discovered by Cassini and Huyghens, two by Herschel, and one by Lassell, at Liverpool, on the same night that Bond observed the eighth, at Cambridge, in the United States. The surface of Saturn shows several obscure bands parallel to the rings, which Herschel attributed to a very dense cloudy atmosphere, and, towards the polar regions, may also be discerned certain white spots, which seem to be indicative of perpetual snow.

III.

Uranus or *Herschel*.—This is one of the largest planets, and, with the exception of Neptune, the farthest from the Earth. It remained lost amongst the fixed stars until the 13th of March, 1781, when Dr. Herschel, then staying at Bath, discovered it.

It is 1,753,851,000 miles distant from the Sun, around

* T. V., p. 356; Leipsic, 1858.

which it accomplishes in 84 years an orbit of about ten milliards of miles, travelling at the rate of 16,000 miles an hour.

The sunlight, which takes 8′ 13″ in its passage to the Earth, must be nearly two hours and three-quarters in reaching Uranus. The intensity of its light and heat cannot be more than $\frac{1}{400}$, of what it is upon our globe, and the Sun's disc must seem no larger than a star of the first order. Seen through the telescope, Uranus has an uniform brilliancy of azure white, and its disc is almost level at the edges. It has a diameter of 33,024 miles, being, therefore, 72 times the size of the Earth. Herschel discovered that six moons circulate around this planet, in orbs almost circular and perpendicular to the plane of the ecliptic.

Neptune.—This is the most remote of the known planets in the solar system.

It has a mean distance from the Sun of 2,746,271,000 miles, taking nearly 165 years to effect its total revolution round that body. The immense distance, and the recent discovery of this planet, are sufficient to account for the slight knowledge which we possess concerning it. It has not, since first discovered, completed more than a sixth part of its orbit, having been observed for the first time but eight-and-twenty years ago.

M. Le Verrier announced its existence in 1846, basing his inductions upon theories drawn from the disturbances in Uranus, and it was actually observed by Galle, at Berlin, on the 23rd of September in the same year.

The cause of the disturbances in Uranus had, however, been guessed at for some time by Bouvard, Hansen, and other astronomers, but the complete solution did not come until 1846. Arago, in his *Report upon the Progress of*

Astronomy (p. 111), says:—"M. Le Verrier perceived the new planet without even taking a look at the heavens; he saw it with the point of his pen, and, by the mere force of calculation, determined the position and approximative size of a body situated far beyond the hitherto known confines of our solar system, of a body more than 2½ milliards of miles distant from the Sun, and which, looked at even through the most powerful glasses, is barely visible. Thus his discovery is one of the most striking manifestations of the accuracy of modern astronomical science. It will encourage the followers of geometry to seek with fresh ardour those eternal truths which, to borrow the expression of Pliny, 'remain concealed behind the majesty of theories.'"

M. Delaunay insists that this discovery must not be confounded with that of several small planets which are situated between Mars and Jupiter, and which have been discovered by closely exploring those regions of the sky near the ecliptic. "The discovery of Neptune, on the contrary, is the result of theoretical researches which have shown in what part of the sky there must be such a planet, and this ascertained, all that remained to be done was to bring the glass to bear on that particular spot." * Nevertheless, Kepler (see page 34) had suspected the existence of some star between Mars and Jupiter long before the discovery of any of the small planets.

The research of the unknown planet, to which the discordance in the observed positions of Uranus and in the tables drawn up by Bouvard, was attributable, became one of the questions of the day, and astronomers generally gave it their attention.

M. Delaunay thus describes the successful research of

* Delaunay's *Report on the Progress of Astronomy.*

Le Verrier :—Having first gone through the calculation of the disturbances in Uranus, due to the action of Jupiter and Saturn, he found it necessary to make several additions to modifications in the aggregate of the disturbances which Bouvard had adopted as the theoretical basis of his *tables.* He then examined a great number of meridian observations of Uranus, taken some at Paris and others at Greenwich, since the discovery of that planet, as well as seventeen observations anterior to its discovery. In this way he deduced the impossibility of considering all these disturbances as resulting only from the influence of Jupiter and Saturn. He then proceeded to examine what part of the sky must be logically occupied by the unknown planet capable of producing the differences which take place in the position of Uranus. Thus he succeeded in fixing the longitude of this unknown planet, first relatively, and then absolutely. The result of these theoretical researches was soon confirmed, and Galle, an astronomer at Berlin, looking for the planet in the direction indicated by Le Verrier, lighted upon it immediately, and at the very spot which theory had assigned to it. This was on the 23rd of September, 1846, and the star, which seemed to be one of the eighth order, received the name of Neptune. It is impossible to have a more striking proof of the precision of our astronomical theories.

"I must add that Le Verrier was not the only person to study this important question, for Mr. Adams was examining it in England at the same epoch. He arrived at the same results, and though those of Le Verrier were published first, both are entitled to share the credit of this astronomical discovery." *

* Delaunay's *Rapport sur les progrès de l'Astronomie*, pp. 13, 14.

CHAPTER XIII.

THE STARS.

Fixed stars—Wandering stars—Number of stars—The stars seen through the telescope—Illusion caused by the aspect of the celestial vault—Distance of the stars from the Earth—Bewildering calculation—The stars nearest to the Earth—Stars of different sizes—The method of classifying and calculating them—Number of stars of each order—The Milky Way—Its nature and shape—From one surprise to another—The rank occupied by our Sun in the creation—Incalculable number of suns—Ideas formerly entertained concerning fixed stars—General motion of the whole solar system in space—The laws of attraction in the most remote regions of the sky—Planetary system of the stars—Double and treble stars—Splendid revelation of spectrum analysis—Elements of which the stars are composed—Types to which they appertain—Ideas concerning immensity, and the stellar bodies which it contains—Division of the stars into constellations—The constellations in ancient times—Historical and legendary ideas—Northern constellations situated above the zodiac—Constellations of the zodiac—Constellations situated below the zodiac.

I.

THE generic word *star* is applied to all the celestial bodies, but the planets have been more specially designated as *wandering stars*, and the name *fixed stars* given to countless twinkling bodies which seem to be distributed throughout the immensity of the firmament, because it was formerly believed that they did not revolve in orbits round a centre, but that they always maintained the same relative situation to each other. It has since been ascertained that many of them have a motion of their own, and the presumption is that such is the case with them all.

Their light is more brilliant than that of the planets, and is incessantly scintillating, that is to say, displaying a tremulous luminosity.

On a fine night there seem to be millions of stars in the sky, yet, even when the firmament is clearest, and at the equator where half of it is visible, it is impossible to count more than two thousand, without a telescope.

If Sirius, the finest star in the sky, is looked at through a telescope of more than a thousand times magnifying power, a tyro will be astonished to find that its volume, far from appearing greater, becomes smaller; for the stars, seen with the naked eye, always seem larger than they are in reality, owing to the diffusion of light around their mass.

The telescope, consolidating the rays, destroys the irradiation, so that the most brilliant star, seen through a good glass, is so infinitely small in extent that we cannot measure it. Thus, the most powerfully magnifying telescope is useless for observing the stars, while it amplifies very much the other bodies to which we apply it such as the Sun, the Moon, and the planets.

If we could rise above the Moon, approach the planets, or reach one of the stars which shine above our heads, we should discover new skies, new suns, new stars, new worlds, perhaps more magnificent than that we now admire.

But the domain of the Creator does not end even there: these are but the frontiers of the infinity of space. We should behold other immensities peopled with other incalculable worlds. And if our journey were to last for tens of thousands of centuries, we should never reach the limit which separates the universe and God. In the presence of such conceptions, calculation and poetry alike are dumb, to use M. de Lamartine's expression, and the boldest inquirer is awed into silence.

II.

The distance of the stars from the Earth is so great that, supposing an observer transported into Sirius, one of the stars nearest to our globe, he would see from there, at an almost imperceptible angle, the whole space of 180,000,000 miles, comprised within the two extremities of the terrestrial orbit, so that the Sun, the Earth, and the Moon, would form but a point, no thicker than a single hair.

If an inhabitant of our globe could ascend to the height of 180,000,000 miles, those three bodies would appear to constitute but three brilliant specks.

We have the proof of this every year. About the 10th of December, the Earth's motion of translation round the Sun brings us more than 180,000,000 miles nearer to the stars in the northern part of the sky than we are on the 10th of June, without our being able to perceive any increase in their size.

Up to the beginning of the fourteenth century, the most diligent studies of astronomers had failed to establish more than the lowest limit of the distance between the Earth and the stars.

Their calculations had demonstrated, by means of *absolute parallaxes*, as this method is termed, that the stars, of which they had endeavoured to fix the distances, must be at least 40 trillions of miles away from us. Such a distance is so difficult of conception, that the astronomers adopted as an unit not the mile, but the space of 186,000 miles, which light traverses in a second.

And as 40 trillions of miles are more than 103 million times the multiple of 186,000 miles, it follows that light, with its enormous velocity of 186,000 miles a second, would take 203 million seconds, that is to say 2,350 days, or 6½ years, to traverse the distance which separates us from the nearest of the stars. It will be found, too, that a cannon ball, with a velocity of 1,650 feet a second, would take more than *four million years* to accomplish the same distance, and that a fast train would take 144 million years.

III.

Another method, called that of *relative parallaxes*, made use of by modern astronomers to measure the distance to the stars, has enabled us to ascertain many distances which it had previously been impossible to determine.

The principal results obtained are as follows: The least distant is the star *Alpha*, in *Centaurus*, which is about 5,865,556,000,000 miles away, and which it would take light nearly four years to reach. Next comes star 61, in *Cygnus*, the distance of which from the Earth would only be traversed by light in 9½ years. After it come the *Alpha* of Lyra, Sirius, Bootes, Arcturus, Capra, etc., the distances of which are traversed by light in 12½, 22, 26, 31, and 72 years.

Now, if we admit, as is often the case in natural sciences, deductions by analogy, we arrive at results even more astonishing.

It may be taken for granted that the stars which appear the least brilliant to us are generally the most remote. Starting upon this hypothesis, and connecting it with the fact that light diminishes in intensity according to the square of the distance, that is to say, appears only a quarter as brilliant at double the distance, a ninth at treble, and so on, astronomers have been enabled to form an approximate estimate of the distance of those stars which cannot be measured directly.

In this way Herschel calculated the relations between the unknown distances. Stars of the second class he calculated to be as a rule four times less brilliant, and consequently twice as far as those of the first order; and the stars in the fourth class to be in turn twice as remote as those of the second. The distance of the stars in the fifth class he estimated to be eight times, and those of the sixth twelve times greater than that which separates us from the most brilliant stars. The faintest which he could distinguish with his ten-foot telescope, would be 344 times farther than the latter; those seen through the twenty-foot telescope, 900 times. And as light takes twenty years to reach us from stars of the first order, it must take *eighteen thousand years* to come from the most remote stars which Herschel could distinguish with his twenty-foot telescope.*

It must be added that this telescope did not penetrate to the farthest limits of the starry sky, for Herschel states that an instrument of forty feet, which does not, however, appear to have been used for a comparison of intensity, added considerably to the number of visible stars. Moreover, it is probable that the celestial regions are not infinitely transparent, in which case many of the fainter stars would not be within the range even of the most powerful instruments. Everything tends to show that these distances quoted are almost microscopic in comparison with the actual dimensions of the celestial regions.

* M. Petit's *Treatise on Astrology.*

IV.

The stars appear to us to differ in size, and they have been divided into seven classes.

The *stars of the first magnitude* are those which appear to us greatest in diameter, and most brilliant; the other stars visible to the naked eye are called stars of the second, third, fourth, fifth, and sixth magnitude, according to their apparent size and brilliancy.

Stars of the seventh magnitude are those which can only be seen through the telescope, and as some of them are more brilliant than others, they are subdivided into stars of the eighth and even the fourteenth magnitude.

The real size of these stars is unknown to us, and their classification, not always very correct, is merely based upon their *apparent* size. This classification was made by early astronomers in a somewhat rough and ready manner, and modern catalogues have not amended the errors.

The most reliable tests give seventeen stars of the first magnitude, but it is impossible to guarantee the accuracy of this estimate. There may be more, and there may be less, for there is no perceptible difference between the last star of the first magnitude and the first star of the second magnitude. These remarks apply with all the more force to the stars of the succeeding magnitudes.

As to their real size, it may well be that those which seem smallest to us are, as a matter of fact, the largest, the size being merely a question of comparative distance.

V.

In the northern hemisphere there have been counted 4,300 stars visible to the naked eye. The operation of counting is performed by piercing a very narrow hole in a screen, and placing it so as to command the stars between the pole and the equator. The stars which appear there in the course of twenty-four hours are carefully noted down, and their totality calculated by means of the following rule: It has been ascertained that the number of stars of the second magnitude is treble that of the primary stars, that stars of the third magnitude are treble those of the second, and so on. Starting upon this basis, we arrive at a total of 43 millions, but this rule evidently fails to give a sufficient number when we come to estimate the stars of the seventh, and still more those of the telescopic magnitude.

Upon part of the constellation of Orion, along a band 15 degrees long by 2 wide, Herschel counted 50,000 stars, a proportion which, if maintained, would give a total of 59 millions for the whole sky.

But there are numerous regions of the sky where the stars are much closer together, to say nothing of the vast aggregations which the nebulæ display.

As we can only discern the first zones of the firmament, and as the stellar strata may be, and no doubt are, piled one upon another almost to infinity in the depth of space, it may well be said that the real number of stars is incalculable.

VI.

Examining the heavens at night, we notice a pale and irregular light, forming a band or zone which extends throughout the sky, and which, termed the *Milky Way* by astronomers, is also known in France as *Le Chemin de Saint Jacques*.

Ovid, in the first book of the Metamorphoses, says: "When the sky is clear a path of very radiant white colour may be seen in the empyrean. It is called the *Milky Way*, and along it the immortals repair to the august dwelling place of the Lord of Thunder."

This luminous track, resembling a light cloud, is formed of countless stars which cannot be seen by the naked eye, but which are visible through a powerful telescope. It is because these stars are so far from us that they are not individually visible to the naked eye, while, between those which can be seen with the aid of a good telescope, are interstices which, to all appearance, are covered with a vast quantity of other stars not within the range of any telescope. The mind becomes confused when we reflect that the stars visible in the milky way, though out of all comparison larger than the earth, appear to us only as luminous points, and no matter what instrument we use they do not increase in volume, which is a further proof of their prodigious distance from the Earth.

The *milky way* comprises luminous matter, which is not resolvable with our comparatively feeble instruments, aggregations of stars, formed perhaps by the disintegration of the *Nebula*, and simple stars of various sizes. Herschel made a minute study of the milky way with his powerful telescope, and while he sometimes observed as many as 600 stars within the arena of his instrument, at others he could only see one. Certain parts of this nebula, as they passed before his telescope, displayed as many as 116,000 stars in a quarter of an hour, and they were succeeded by sections that did not contain a single one. In fact, so far as we can judge, the milky way exhibits patches of diffuse luminous matter, and many millions of stars, some isolated, others massed in groups, and forming in its totality a kind of zone or ring, the diameter of which would be about six times greater than its thickness, and of which our Sun would form a part.

VII.

Herschel was led to conclude that the numberless stars which compose the milky way constitute a mass of a more or less lenticular form—the section of a sphere or a carriage wheel, with the Earth at about the centre, and with a thickness not more than the sixth of its diameter. Now, such a mass as this would be likely, considering the profundity of space, to present a spot of whitish colour, standing out upon the background of the sky, and this appearance is as a matter of fact presented by a multitude of small nebulosities which powerful glasses have discovered in the firmament, and which are at scarcely perceptible angles to the Earth.

Some of these spots, of these five thousand and more nebulæ, which have been catalogued, are certainly equal in size to the nebula of which we form part, and the astronomers who have attempted to calculate their distances have arrived at figures which almost inspire a feeling of terror. It has been estimated that light would not traverse the distance between these nebulæ and the Earth in less than *sixty million years*, while a cannon ball would take 37,000 *milliards of years!*

And yet, M. Petit adds, there is no reason for supposing that the created universe ends here. On the contrary, there are a thousand motives for believing that if we could be transported to these remote regions, we should find the limits of the firmament as distant as ever, with now unknown stars shining in another infinity of space.

Having ascertained the distance of certain stars, it was relatively easy to determine the rank which our Sun occupies in creation. This luminary, with a volume thirteen hundred thousand times greater than that of the Earth, would, if transported into the mean region of stars of the first magnitude—that is to say, a million times more distant than it now is—appear to us as a scarcely visible speck, as a very small star of the fifth or sixth magnitude.

Thus the stars are themselves suns, and much larger, as a rule, than that which illuminates our globe. Struwe has calculated upon the data given by Herschel, that in the milky way alone there are at least 20 millions of visible suns, independently of those, far more numerous no doubt, which we cannot discern there. Yet the milky way occupies but a small corner of the universe, for astronomers have already counted more than five thousand nebulæ, several of which, it appears certain, are as extensive and fully peopled with suns as the milky way!

VIII.

The stars maintain, in relation to each other, positions which were formerly considered as invariable; whence their denomination of *fixed* stars. Ancient astronomers thought that they were luminous points, adherent to the celestial vault, and travelling with it every day in a common motion from east to west.

It was not till the beginning of the eighteenth century that the displacement of these celestial bodies was deduced from a study of past records. In 1738, Jacques Cassini demonstrated the change of position of *Arcturus*, and of *Alpha* in Aquila; and in 1756 Tobie Mayer discovered that of eighty other stars. Since then the discoveries have been so multiplied that what seemed a paradox a hundred years ago is now a generally accepted truth, so much so that, in 1845, "the British Association for the Advancement of Science" published a list of more than eight thousand stars, three-fourths of which possess calculated motions of their own. It is marvellous to think that millions of globes similar to our Sun, *twelve or fifteen hundred thousand times* more voluminous than the Earth, are travelling through the immensity of space without coming into contact, at a speed far greater than that of a cannon-ball, and yet appearing to us quite motionless, except by the aid of the most powerful instruments. We may well exclaim with the psalmist: "The heavens declare the glory of God!"

After a number of calculations based upon the motion of the stars, and very minutely carried out, Sir William Herschel succeeded in proving that the Sun moves with the Earth towards those stars which seem gradually to increase the distance between each other, and that on the other hand it recedes farther away from those which appear to draw closer together. Subsequent to 1783, when his researches were made, numerous facts have come to light, tending to confirm the truth of this theory. The best authenticated data attribute to the Sun, and therefore to the Earth and the whole solar system, an annual progress of nearly 300,000,000 miles towards the stars γ and δ, of the group known as the constellation of Hercules. This gives a daily progress of about 800,000 miles.

IX.

The laws of attraction extend to the most remote regions of the sky, and Herschel was the first to observe in many of the binary groups the mutual dependence of two stars upon each other; to these he gave the name of *double stars*. Something analogous appears to take place in the groups, of which, however, there are not so many, formed of three, four, or even a greater number of stars, which have been termed *multiple stars*. From the few motions which it has been possible to observe, it has been ascertained that the *satellite star* describes around the *principal star* an ellipse of which the latter does not occupy the centre.

The two stars which together constitute a double star, move around each other, and M. Delaunay says that this common motion was traced by Savary about forty years ago to the great law of universal gravity. M. Yvon Villarceau also took up this important question, and he has drawn up new formulæ for determining the orbits of the double stars, and has put it into practical application for several of them.

Father Secchi says: "The stars are divided into groups, which form systems similar to that to which we belong. The laws of attraction produce and regulate the motions of these distant bodies, as well as the circulation of the planets round the Sun. The simplest systems constitute the double or treble stars; they are so many suns with their cortège of planets describing elliptic ellipses around them. These planets only differ from ours in one respect; they are still incandescent, and therefore luminous of themselves, reflecting their own light to us, and not that which they reflect from other bodies. This circumstance permits us to see them from so great a distance, to observe the positions which they successively occupy, and to calculate the orbits which they describe." *

We are even in the way of discovering that the stars have

* Father Secchi on *The Sun*, p. 404.

obscure satellites. The irregularities observed in the motion of Sirius had long raised the suspicion that some similar body must circulate around this magnificent star; but when this satellite was discovered it proved to be luminous of itself, and as brilliant as a star of the sixth magnitude. It is, however, shrouded by the dazzling brightness of Sirius. Another star, *Algol* (β of Perseus), also affords us direct proof of the existence of obscure satellites by the regular variations to which it is subject, and which can only be occultations produced by an opaque body passing across the luminous star. These variations are phenomena identical in character with our eclipses, a fact which, long guessed at, has been placed beyond doubt by recent spectroscopic discoveries.

The name of *double stars* has also been given to those which are near enough to influence each other through gravity, and to form a separate system. So far we only understand fifteen of these systems sufficiently well to be able to fix with precision their revolutions, and to calculate the elements of their orbits; but there are a great many others. Further researches will unquestionably augment the number of binary and tertiary systems. The binary systems present two remarkable peculiarities; their orbits are generally very elongated, and the two stars have nearly always complementary colours, which indicate a difference of temperature, and a different state of condensation. Moreover, as Father Secchi remarks (*The Sun*, p. 407), there are groups of stars in the sky which we must recognise as forming symptoms physically connected, as, for instance, the Pleiades, the group of Cancer, that of Perseus, certain immense nebular spaces, such as the Coma Berenices, the Magellanic clouds, and especially the Milky Way.

X.

One of the most remarkable points connected with the stars is the periodical variations which many of them undergo; for instance, one of them situated in the neck of Cetus seems to be of the second magnitude when at its brightest, preserving these dimensions and brilliancy for a fortnight, then gradually diminishing until it disappears altogether, only to reappear three hundred and thirty days afterwards.

Another, in the breast of Cygnus, has a period of fifteen years; it appears during five years, with variations of brilliancy and size, and then becomes invisible for ten years. Another, in the beak of Cygnus, has a period of thirteen months; and in 1770 and 1771 another star was observed in the same constellation, which disappeared in 1772, and has not been seen since.

The star discovered in 1704, by Maraldi, in the constellation of Hydra, appears during four months, and then vanishes, only to reappear twenty months afterwards. Its period, therefore, must be two years.

Several astronomers think that these stars are not brilliant all over their surface, and that, turning upon their axis, they present to us at one time their luminous, and at another their obscure hemisphere. Others argue that opaque bodies circulate around these stars, and from time to time become interposed between them and the Earth.

However this may be, such phenomena indicate great activity in regions from which we might be inclined to think that life and motion were utterly excluded.

There is a mass of undisputed evidence, dating from the most remote times, to show that certain stars were in former days more brilliant than some others, which are now in turn far brighter than the first. In the days of Eratosthenes, Antares was less brilliant than one of the two stars in Libra; but within the last century alterations of this kind falsify in several constellations the order of the stars, as arranged according to the letters of the Greek alphabet, in comparatively modern catalogues.

XI.

Spectrum analysis has disclosed to us the elements of which certain stars are composed, and I will append a succinct account of the reliable results which Father Secchi has arrived at in his study of this subject.

For the purposes of spectrum analysis the stars belong to four perfectly distinct types, though certain of the spectra seem rather to serve as connecting links between the classes than to belong to any one of them. The *first type* is that of stars generally called *white*, though in reality they have a slightly blue tint, such as Sirius, Vega, Altair, Regulus, Rigel, etc.

These stars have a spectrum formed of the usual group of the seven colours, traversed by four thick black lines, one in the red, another in the greenish-blue, and the two others in the violet. These four rays are characteristic of hydrogen, and they coincide with the four more brilliant rays which are visible in the spectrum of this gas when it is raised to a high temperature. Other rays reveal the presence of sodium, magnesium, and iron. The most notable peculiarity in this type is the breadth of certain rays, a fact which tends to show that the absorbing stratum is very thick, and subject to great pressure.

Nearly half of the stars in the sky belong to this type.

(For the classification, see Chromolithograph, No. II., Chapter 3). The *second type* is that of the yellow stars, the spectrum of which is exactly similar to that of our Sun, showing some very thin, black rays, close together; this type comprises Cassia, Pollux, Arcturus, Aldebaran, Procyon, &c., nearly two-thirds of the remaining half. The stars in this second category, having the same composition as the Sun, are in the same physical condition.

The *third type* is that of stars approaching red or orange in colour, such as α of Hercules, β of Pegasus, o of Cetus, α of Orion, Antares, &c. Their spectrum is composed of a double system of nebulous bands and black rays, the latter being the same as in the second type. Most of the dominant rays in this type belong to metals which have been observed in the Sun, such as magnesium, sodium, and iron, and those appertaining to hydrogen have also been remarked. This spectrum is in all points similar to that of the solar spots, which would seem to indicate that the stars of the third type only differ from those of the second in the thickness of their atmosphere and the want of continuity in their photospheres, and that they have spots like those of the Sun, but incomparably larger.

The *fourth type* appertains to small stars of a blood-red colour, which are by no means numerous. Their spectrum contains three fundamental zones, red, green, blue. Some of the chief black rays very nearly coincide with those of the third type. The very few stars in the fifth category show a *direct* hydrogen spectrum.

To conclude this portion of my subject, I will quote the following remarks by Father Secchi:. "What are we to think of these vast expanses and the stars with which they are peopled; stars which are, no doubt, like our Sun, centres of light, heat, and activity, destined, like it, to sustain the life of countless creatures? It would be absurd for us to imagine that these vast regions are untenanted deserts; they must be peopled with intelligent and reasoning beings, capable of knowing, honouring, and loving their Creator; beings, perhaps, more faithful than we are towards Him who raised them up out of nothingness." *

XII.

DIVISION OF STARS INTO CONSTELLATIONS.

To facilitate their study, stars have been divided into constellations, which have received the names of men, animals, and mythological objects.

The different stars forming a particular constellation have been designated by the letters of the Greek alphabet, the letter *a* being the most brilliant, and so on.

The Chaldæans are generally looked upon as the earliest astronomers, and they were the first to classify the known stars into constellations. The book of Job refers to the *Secret Chambers of the South*, which may be taken to signify the constellations near the South Pole, and it is generally supposed that the Sacred Book contains an allusion to Scorpio and Taurus. The only constellations alluded to either in the Book of Job, Homer, or Hesiod, are Ursa Major, Bootes, Orion, Canis Major, the Hyades, the Pleiades, Scorpio, and Taurus.

In the year 125, B.C., Hipparchus made a catalogue, supposed to be the first ever compiled, of the stars, with a description of their size, position, longitude, and latitude.

The following are some of the legends attached to the

* Father Secchi on *The Sun*, p. 418.

names bestowed on the constellations, many of which are taken from Ovid.

The nymph Callisto, one of Diana's attendants, had offended Juno, who took vengeance upon her, by changing her into a bear. Though thus transformed, she still retained her natural instincts, and, herself a beast of the forest, fled with terror from the others. Her son Arcas, whom she had borne to Jupiter, was hunting one day in a wood, and not recognising his mother in the she-bear, was about to slay her, when Jupiter warded off the blow, and whirling them both into space, changed them into two neighbouring constellations: *Ursa Major and Ursa Minor.*

Cassiopea, the wife of Cepheus, King of Æthiopia, and mother of Andromeda, having boasted that she was more beautiful than the Nereides, Neptune sent a sea monster to ravage Æthiopia; and to appease him Andromeda was exposed to a rock, but delivered by Perseus, whom she afterwards married. Jupiter placed Cassiopea in the rank of constellations.

Perseus, the husband of Andromeda, was the son of Jupiter and Danaë; he slew Medusa, the most formidable of the three Gorgones, built the city of Mycenæ, and after his death he also was placed amongst the constellations.

Cepheus, son of Phœnix, King of Æthiopia, espoused Cassiopea, who bore to him Andromeda. He accompanied the Argonauts in their expedition after the golden fleece. At his death he was placed by the Gods in the constellations, so that he might be with his wife and daughter.

The famous horseman, Trethon, King of Athens, was the first man who drove four horses abreast, and as a reward Jupiter put him amongst the constellations. He is termed the *Waggoner* (Charles' Wain).

Lycaon, having served up his grandson Arcas to Jupiter, whom he was entertaining, the divinity resuscitated him, and placed him in the constellations. He is called *Bootes*, or *Arctophylax, the bear-keeper.*

Berenice was the wife of Ptolemy Euergetes, King of Egypt. Her husband having undertaken a perilous expedition, Berenice made a vow to consecrate her hair to Venus if he came back in safety, and on his return cut it off, and deposited it in the temple. The hair having disappeared soon afterwards, Conon, the astronomer, to curry favour, insinuated that Jupiter had placed it amongst the stars. This is the constellation termed *Coma Berenices.*

Arion, a famous lyric poet and musician, was a son of Cyclos of Methymna. He amassed great wealth by his profession, and on his return from a voyage to Sicily the sailors resolved to murder him for his money. They allowed him, however, to play some tunes before putting him to death; the music attracted the Dolphins, and Arion, jumping overboard, was carried on the back of one of them to Tænarus, whence he hastened to Periander, who crucified the sailors when they reached the port. At the request of Apollo, the god of music, Jupiter made *the Dolphin* a constellation of nine stars.

The Emperor Adrian was very much attached to a young man of great beauty, called Antinous, who gave himself up as a voluntary sacrifice to propitiate the gods. Adrian, in remembrance of his self-devotion, raised a temple to him, and named after him a recently-discovered constellation.

Venus and Cupid, to escape from the giants that were pursuing them, transformed themselves into fish, and swam across to Syria. This is why the Syrians at one time refrained from eating fish, and is the origin of the constellation *Pisces*.

A ram with a golden fleece saved Phryxus and Helle from the wrath of Ino, daughter of Cadmus, their step-mother. Phryxus immolated this ram to Jupiter, and suspended his fleece in the temple. Jupiter accepted the sacrifice, and placed *Aries* in the constellations.

Castor and *Pollux* were the sons of Jupiter and Leda. Castor having been killed at the siege of Sparta, his brother implored Jupiter to bestow upon him half of his own life, so that each should live on alternate days, and the Thunderer recompensed this rare display of fraternal affection by placing the two brothers in the sky.

Cancer was made a constellation at the prayer of Juno, because it had been killed by Hercules, for having bitten him in the foot during his combat with the hydra of Lerna.

Orion represents one of the most beautiful constellations in the sky. He was a famous giant and hunter, the reputed son of Hyrieus, a Bœotian peasant; but really the son of Jupiter, Neptune, and Mercury, who having been hospitably entertained by the widower Hyrieus when travelling in disguise, granted him a son by ordering him to bury, full of water, the skin of the ox sacrificed to them. In this skin was subsequently found Orion, who demanded in marriage the daughter, Hero or Merope, of King Œnopion of Chios. He afterwards became an attendant of Diana, who conceived a deep passion for him, but Apollo, indignant at her love for a mortal, asked her to shoot at an object in the sea, which turned out to be Orion. He was afterwards placed in the sky as a constellation, seventeen stars forming the figure of a giant, with a girdle, sword, and lion's skin about him.

Orion boasted that he could subdue the fiercest monsters, and another legend recounts that he was killed by the bite of a *Scorpion*, which was placed in the heavens as a warning to men against being boastful. Orion's dog had such great speed that he surpassed all the other animals, but being pitted against a fox to which Jupiter had given an equal degree of speed, he was carried up into the heavens, lest the Fates should be unpropitious to him. This is the constellation of *Canis Major*.

The constellation *Canis Minor* is so called in memory of a dog for the great grief he had exhibited at the death of Icarus, his master.

Phaethon, son of Phœbus and Clymene, once asked permission to drive the chariot of the Sun one day in the sky, but taking the horses out of the track, he nearly set the universe on fire, and was precipitated by Jupiter into the Eridanus (R. Po). This is why that river was placed amongst the constellations.

Chiron, a centaur, was famous for his love of music, medicine, and shooting, and he had for his pupils the greatest heroes of the age, such as Achilles, Æsculapius, Hercules, Jason, Peleus, Æneas, &c. He was accidentally wounded in the knee by Hercules with a poisoned arrow, while pursuing the centauri, and having in his agony prayed Jupiter to deprive him of his immortality, he was placed by that god as the constellation *Sagittarius*. In the same region of the sky are the three following constellations:—*Corvus* and *Serpens*, with the sign of *Crater* (the Cup) between them. The following legend attaches to all three:—Phœbus, who was preparing a solemn feast for Jupiter, sent a crow, his favourite bird, to fetch some spring water in a golden cup. The crow, attracted by some figs growing on a tree, which were not yet ripe, sat perched on a tree waiting until they came to maturity, and, to conceal his misconduct, flew back to Phœbus with a large serpent in his claws, which he declared had prevented him from taking any water out of the spring. Phœbus, to punish him for his double fault, decreed that as long as the figs hung on the tree, he should not be allowed to taste any water, and he let the *cup* stand full of water, with the *serpent* close by, to prevent the *crow* from tasting it.

The goat which was reared with Jupiter on Mount Ida scattered terror amongst the Titans, who were attempting to escalade Olympus. The gods, struck with terror, changed themselves into different kinds of animals, Diana into a cat, Apollo into a stork, Mercury into an ibis, Pan into *Capricornus*, which is now one of the signs of the Zodiac.

Ganymede while hunting on Mount Ida was carried away by an eagle to Jupiter, and became cup-bearer to the gods. Hence the constellation *Aquarius*.

Hercules, while travelling with his wife Deianira, came to the river Evenus, which was overflowing its banks. The centaur Nessus offered to convey them across, and took Hercules first, and then attempted to carry off Deianira. Hercules shot him with a poisoned arrow, and the dying centaur, wishing to be avenged, gave Deianira his tunic, covered with his poisoned blood, and told her that it would at any time reclaim her husband's affections if he should prove faithless. Some time afterwards, while he was raising an altar to Jupiter, on Mount Œta, she sent it to him as a philtre, not knowing it was poisoned. When Hercules put it on he was attacked with incurable pains, but he mastered the agony sufficiently to erect a large funeral pile, which Jupiter surrounded with smoke, and when his mortal parts were totally consumed he was carried up to the heavens and placed amongst the stars.

There is no need to relate the well-known allegories of *Orpheus* bewailing his beloved Eurydice on the *Lyre;* of the *Dragon* keeping watch over the garden of Hesperides; of *Cygnus* and *Taurus*, into which animals Jupiter changed himself; of the *Lion* slain by Hercules in the forest of Nemea: all mythological figures which have lent their names to constellations.

XIII.

NORTHERN CONSTELLATIONS SITUATED ABOVE THE ZODIAC.

1st. *Ursa Major* or *Charles' Wain.*—This constellation is composed of seven bright stars, four of which form a square, and the other three, representing the *tail* of the bear, or the *pole* of the waggon, a curved line.

Six of the seven stars in *Ursa Major* are of the second magnitude, or *secondary;* the seventh, a *tertiary* star, is at the angle of the square from which the *tail* of the bear springs.

The two stars forming the short side of the square opposite to the tail are called the *Guardians*. The bear's *paws* are represented by stars situated between *Ursa* and *Leo*.

2nd. *Ursa Minor*, or the *Little Wain*, nearer to the pole than *Ursa Major*, is also formed of seven stars, forming a somewhat similar figure; but they are less brilliant, and the figure is not so distinct as in *Ursa Major*, being also turned in an opposite direction.

The star situated at the extremity of its tail is called the *Polestar*, and it is a bright *secondary* star, 1° 39′ from the pole. It is all the more easily noticed, as being the only secondary star in this region of the sky, and as it is in the direction of the *Guardians* of *Ursa Major* it can be discerned at once by drawing an imaginary straight line through the two Guardians.

3rd. *Cassiopea* is situated upon the other side of the pole relatively to *Ursa Major*, and is easily to be distinguished by its five *tertiary* stars in the shape of the letter M.

4th. *Cepheus* is formed of three *tertiary* stars in the shape of a bow, and of five stars of the fourth class; it is nearer to the pole than Cassiopea. The prolongation of the line from the *Guardians* of Ursa Major, which enables us to fix the Polestar, passes to the north of the bow of Cepheus.

5th. *Draco.*—This constellation displays a long row of doubly sinuous stars. The *tail* of the Dragon separates the two *Ursæ.* The body folds round Ursa Minor, first approaching near to Cepheus, and then folding back almost on to the *head,* which is formed of four stars, which is easily visible by continuing the straight line through Cepheus and Cassiopea.

6th. *Pegasus* has the shape of a somewhat elongated square, of which the corners are four secondary stars. If a line be drawn from the Guardians of Ursa Major to the Polestar, and thence prolonged twice as far, it will pass through the square of Pegasus, which is on the opposite side of the pole to Ursa Major.

7th. *Andromeda* is the most northerly of the four corners in the square of Pegasus. The straight line between it and the Polestar passes through the most brilliant star in the constellation of Cassiopea. It comprises three *secondary* stars, almost equi-distant, and forming a slightly curved line.

8th. *Perseus.* The most brilliant star in Perseus, which is of the *second order*, is situated between two *tertiary* stars, the three forming an arc slightly convex towards Ursa

Major. From the extremity of this arc start two rows of stars, the one running eastward towards Capella, and completing the arc of Perseus; the other southward, pointing, after a bend in the opposite direction, in a straight line towards the Pleiades.

Underneath the most brilliant star in Perseus is *Algol*, or *Medusa's Head.* This star is a variable one, remaining for two and a-half days as a *secondary* star, when its brilliancy suddenly fades, and in the space of three hours it becomes a star of the *fourth magnitude;* soon, however, to regain its former brilliancy.

9th. *Auriga* is a large irregular pentagon, situated to the east of Perseus. The three most brilliant stars form an isosceles triangle; the apex, which is also one of the horns of *Taurus*, is at the base, and the base contains the star of Capella in the continuation of the belt of Perseus.

Abhaiot, or *Capella*, is a star of the first order. Close to it are three small stars called the *Capri*, forming an isosceles triangle.

10th. *Lynx* is a constellation of no great importance, situate between Auriga and Ursa Major, below the latter.

11th. *Leo Minor*, composed of six stars, is upon the southern section of the line, drawn from the *Guardians* of Ursa Major.

12th. The *Triangular Borealis* is formed of three stars in the shape of an isosceles triangle, between the foot of Andromeda and Aries.

13th. *Camelopardalis*, a scarcely visible constellation, is between the Polestar and Auriga.

14th. *Bootes* contains a star of the first magnitude, called *Arcturus*, situated in a somewhat curved line beyond the tail of Ursa Major.

Close to Arcturus, and to the north-east, is the irregular pentagon of *Bootes*, the three northern stars of which form an isosceles triangle. The raised hand of Bootes is formed of four stars of the fourth order, situated close to the extremity of the tail of Ursa Major. By this hand Bootes holds two *greyhounds*, situated under the tail of Ursa Major, and the neck of one of them contains a tertiary star known as *Cor Caroli*.

15th. *Coma Berenices* (which is also called the *Wheat-sheaf*) is composed of a group of small stars very close to each other, and it is situated between Virgo and Cor Caroli, below Ursa Major, and near the tail of Leo.

16th. *Corona Borealis* is composed of thirty-three stars, six or seven of which form a semicircle, with its concave surface facing the head of Draco. The most brilliant of these is of the third magnitude, and is called *Clara Coronæ*.

17th. *Lyra* is composed of twenty-one stars, one of which is a splendid primary star called *Vega*, forming, with two other tertiary stars, an isosceles triangle, which renders it easy of recognition.

18th. *Aquila*, or the *Eagle*, is situated to the south of Lyra. It is easily distinguished, as it contains three remarkable stars in a straight line. The middle one is called Altair, and is of the first magnitude; the other two being of the second.

19th. *Cygnus* or *Crux*, is composed of five principal stars, which form a cross in the milky way. The most northerly of these stars is of the second magnitude, and is known as the *tail* of Cygnus. The most southerly one, which is of the third class, is called the *beak* of Cygnus. This constellation is situate eastward of Lyra, and diametrically opposite to Gemini in respect to the poles.

20th. *Serpens* and *Serpentarius* (or *Ophinchus*).—These two constellations occupy a vast expanse in the sky. The *head* of Serpentarius is indicated by a secondary star. The *head* of Serpens is situated below Corona Borealis, and resembles the letter Y, the tail of which is formed of two tertiary stars, between them being the *heart* of Serpens, which is also a secondary star. The rest of the body is formed of a row of *tertiary* stars, and extends to some distance below the equator.

21st. *Sagitta* is composed of eighteen stars of the fourth and fifth magnitude, and is close to Aquila, between Altair and the foot of the cross in Cygnus.

22nd. *Hercules.*—The main part of this constellation is formed of a quadrilateral of four stars in the fourth category. A straight line drawn from Vega to Clara Coronæ intersects the quadrilateral of Hercules, which is equi-distant from them both. The *head* of Hercules, which is a tertiary star, is close to that of Ophinchus.

23rd. *Delphinus* is a constellation composed of five principal stars, one of which is *tertiary*, and to the south of the four others, which form a small lozenge.

24th. *Antinous* is just below Aquila, and is composed of six principal stars, four of which form a quadrilateral. The eastern one is in a straight line with the three stars in Aquila.

25th. *Equuleus* is between the constellations of Aquila and Pegasus, and is composed of four stars, which form an irregular square, the longest sides of which extend from north to south.

XIV.

SIGNS OR CONSTELLATIONS OF THE ZODIAC.

1st. *Pisces.*—This constellation, in degree 342 of the ecliptic, extends from 18° to 36°, which is the equinoctial point, and the beginning of the sign of Aries. The Pisces extend 42° farther, so that they embrace altogether 60°, or the expanse of two signs. The first twelve degrees of this constellation also belong to Aquarius, and its last to Aries. It is composed of two stars; one, called *Piscis Orientalis,* is situated above the ecliptic, beneath Andromeda and Triangulus; the other, called *Piscis Occidens,* is close to the ecliptic. The Pisces are connected by two rows of very small stars, both of which are united to a tertiary star or node.

2nd. *Aries* occupies only 20° 17′ in the sign of Taurus, and contains only three important stars. It forms a sort of circumflex accent above the ecliptic.

3rd. *Taurus* occupies 10° in the sign bearing that name, and 22° in the sign of Gemini, which contains its *head.* The head of Taurus forms a letter *V,* with its base towards Aries, and its two points towards the milky way. One of these points is marked by a bright star of the first order, called *Aldebaran,* or *The Eye of Taurus,* which is contiguous to a small star near the milky way. The other point is indicated by a star of the second order, and the two represent the horns of Taurus.

4th. *Gemini.*—This sign is a long and irregular quadrilateral, formed of four principal stars, two of which are secondary, and situated to the east of Taurus. They represent the *feet* of the Gemini, the heads being indicated by two bright stars. Castor, a star of the first order, is situated to the north, nearest to the pole and the milky way. Pollux, a star of the second order, is farther removed.

5th. *Cancer* is composed of stars which are not easily distinguished. It is between Gemini and Leo.

6th. *Leo* occupies 38° in the zodiac, and has four brilliant stars forming a large trapeze beneath Ursa Major. A straight line drawn from the two stars in the square of Ursa Major nearest to its tail would, if prolonged, intersect *Regulus*, or *the heart* of Leo, which is a very bright star of the first class, situated just above the ecliptic. The head, which is higher up, and is composed of four small stars bordering on Cancer, contains one brilliant star.

7th. *Virgo.*—A long diagonal line drawn southwards from the square of Ursa Major, strikes a brilliant star of the first class known as the *Spica Virginis*. This constellation is in the shape of a very open letter *V*, and is made up of five tertiary stars, of which the one nearest to *Coma Berenices* is called *Vendemiatrix*.

8th. *Libra* is upon the continuation of a straight line drawn from Regulus in Leo to Vendemiatrix in Virgo. Two bright secondary stars form the two *scales* of Libra, and two other tertiary stars give it the shape of an oblique quadrilateral.

9th. *Scorpio* is composed of six principal stars, very symmetrically situated, three of them form an almost straight line from north to south, and three from east to west. The middle star of the three latter, of the very first class and very brilliant, is called *Antares*, or *the heart* of Scorpio.

10th. *Sagittarius* is the constellation which follows next after Scorpio across the meridian. Very easily distinguished, it is partly in the milky way, and is in a direct line between the central parts of Cygnus and Aquila.

11th. *Capricornus,* composed of five principal stars of the third magnitude, is to the east, in a line drawn from the beak of Cygnus, and passing close to the head of Aquila.

12th. *Aquarius* is not very easily discerned, as its brightest stars are only of the third order. It is just to the east of Capricornus, and extends from Delphinus to *Fomalhaut* or the mouth of Piscis Australis.

XV.

PRINCIPAL CONSTELLATIONS BELOW THE ZODIAC.

1st. *Orion* is the most remarkable constellation in the sky. It is composed of eleven principal stars, two being of the first magnitude, four of the second, two of the third, and three of the fourth and fifth. It is situated below Auriga, between Gemini and Taurus, and is in the shape of a large quadrilateral, the diagonals of which are formed of two secondary and two primary stars. At the north-east angle is the right shoulder, a star of the first order, and at the south-west angle is the left foot, represented by a star of the first magnitude, called *Rigel.* In the middle of the quadrilateral are three stars of the second magnitude, called the *belt* of Orion, or *the girdle,* the *Three Wings,* the *Rake,* or *Jacob's ladder.*

2nd. *Cetus* is a large constellation to the south of Aries, and below the region which separates the Pleiades and Pegasus.

3rd. *Corvus* is in the shape of a large trapezium, and is composed of four principal stars, to the south of Virgo, close upon the line from Lyra to Spica Virginis.

4th. *Lepus* forms a quadrilateral of four stars, of the third magnitude, just below Orion, and to the right of Canis Major.

5th. *Crater* is situated to the rear of the hind feet of Leo, and is composed of stars of the fourth magnitude, which form a semicircle, to the right of Corvus. Other stars below the semicircle form the base of the cup (*Crater*).

6th. *Hydra* occupies the quarter of the horizon below Cancer, Leo, and Virgo. To the left of *Procyon* is *the head* formed of four stars of the fourth order. A line drawn from the western side of the great trapeze of Leo, will meet the primary star, *Alfraf*, or *the heart* of Hydra. A row of ten stars composes the folds of Hydra, who carries on his back Corvus and Crater.

7th. *Eridanus*, composed of a long train of stars of the third and fourth classes, begins at the feet of Orion, close to Rigel, bends back upon itself below Taurus and Cetus, and terminates beneath the horizon with a star which is invisible at Paris.

8th. *Canis Minor*, situated between Hydra and Orion, comprises a brilliant star of the first order, called *Procyon*, to the north of Sirius and below the Gemini. A tertiary star, close to the feet of the Gemini, represents the jaws of Canis Minor.

9th. *Canis Major*, situated at the feet of Orion, is mainly composed of five secondary stars and Sirius, the latter being the largest and most brilliant in the whole sky.

Fig. 55.—Dioscuri (Castor and Pollux).

CHAPTER XIV.

THE COMETS.

Description of a comet; its different parts—The nature of comets—The opinions of modern and ancient astronomers—Terror which comets formerly inspired—Recent comets—Periodic comets—Changes to which comets are liable, both in regard to their shape, motion, and course—Their volume and mass—Possibility of a comet coming into contact with the Earth—Result of the shock—Density of the various portions of a comet—The passage of the Earth through the tail of a comet—Account of the chief periodical comets—The comets of Halley, Encke, Biela or Gambard, Faye, Brorsen, d'Arrest, Tuttle, and Winnecke.

I.

THE etymology of the Greek word *comet*, is a *hairy star.* The luminous point generally visible about the centre of a comet is called the *nucleus.* The sort of luminous aureole which encircles the nucleus is known as the *hair* of the comet. The nucleus and the hair together form the *head.*

The luminous trains varying in length, which form part of most comets, are known as the *tails.*

Nearly all these comets appear only in the shape of vaporous masses, either round or slightly oval, denser towards the centre, but without distinct masses or anything that can be called a solid body.

The stars remain visible even when they are covered by the apparently densest part of a comet, yet the lightest of clouds conceals them from our view altogether. But in certain comets a solid nucleus, extremely small, has been observed by means of very powerful telescopes.

The extraordinary volume of the comets is probably due to the slight amount of attraction which the very diminutive nucleus exercises upon the elasticity of the gaseous particles, the force of attraction being, as we know, in direct ratio to the density of the mass, that is to say, that the more molecules a body contains in the same volume, the more powerful is its attraction upon the surrounding bodies. If the Earth were to diminish in density, the atmosphere would at once extend very much farther. The nature of the comets is still an unsolved problem. At the same time it has been ascertained that most of those which have been brought under examination circulate around the Sun, like the planets, in obedience to the laws of Kepler, but they describe very eccentric ellipses, the planes of which instead of being almost merged in the ecliptic, as is the case with the principal planets, present an infinite variety of inclinations. The comets change in aspect from day to day, and they cannot well be identified from their appearances. Therefore, to establish the identity of a comet at its various apparitions, we must have recourse to mathematical calculations.

Most of the ancient philosophers looked upon comets either as atmospheric meteors, or passing celestial phenomena. Some of them held that they were, like the shooting stars, terrestrial exhalations which took fire in the regions of flame; others considered them to be the souls of illustrious men ascending to heaven. But Pythagoras appears to have formed a fairly correct idea as to their nature, for he maintained that they were actual stars moving round the Sun, yet even he never suspected the elliptic nature of their orbits. The first reliable demonstration of the planetary motion does not date back beyond the close of the 16th century.

II.

Sir William Thomson, in his speech at the Edinburgh meeting of the British Association in 1871, referring to the present state of our knowledge on this subject, said:—

"Great progress has been made of late years towards the discovery of the nature of comets, and the truth of an hypothesis which has long seemed plausible to my mind is now almost certain; viz., that they consist of meteoric stones. This supposition accounts satisfactorily for the light of the nucleus, and furnishes a simple and rational explanation of the tails of comets which have been regarded even by the greatest astronomers as bordering upon the supernatural."

It is needless to remark that this opinion does not meet with universal acceptance, and it furnished the subject of a long debate in the French Académie des Sciences in the following October. M. Faye, in his work on comets, and what we at present know about them, says:—

"Subsequent to the researches referred to in the first portion of this work, two new facts have been brought to light. Huggins has discovered in the spectrum of the nucleus of certain comets, luminous rays which he attributes to the incandescence of carbonised vapours. Upon the other hand, the researches of Schiaparelli, Newton, Le Verrier, Peters, Adams, and others, have shown that certain periodical clusters of shooting stars are closely connected with certain comets also periodical, for these clusters and the corresponding comets follow exactly the same course in the sky. Tait has deduced from these two facts alone a whole theory concerning the phenomen of comets. He coincides with Sir W. Thomson in thinking that comets are mere aggregations of aerolites, the mutual encounters of which would engender the light that Huggins has observed, and that there are only a portion rendered visible for a brief moment of the cluster of shooting stars which must accompany every comet. This second supposition would upset all the hitherto-received theories and observations, and I only notice it to point out that if Schiaparelli's discovery has, so to speak, given us the key to the enigma of shooting stars, it is quite silent as to the comets themselves. This is a question of common origin very unexpectedly asked, and as wonderfully answered: the tails of the comets have nothing to do with it. As to the first point in Mr. Tait's hypothesis, it seems very plausible, viz., that the light emitted by the nucleus may be produced by the encounter of two comets."

I must add that Delaunay in his *Treatise upon the Progress of Astronomy* considers the *shooting stars* as small comets, moving through space in clusters.

III.

In the early ages, comets, appearing only at rare intervals, and being of a shape so different from the other stars, created almost universal alarm. Their existence—apart, so to speak, from the regular stars in the sidereal regions—the singularity of their motions and their peculiar shape, explains this feeling of terror at a time when science had not as yet laid bare the mysteries of the firmament. They were looked upon as the presage of great calamities, and it was said that the death of Julius Cæsar was announced by the comet which appeared in the year 14 B.C.; the cruelties of Nero by that of A.D. 64, and the origin of Mahometanism by the comet in 603, because its tail was in the form of a scimitar. The comet of 1240 was looked upon as the forerunner of Tamerlane's invasion, and the fall of the Greek empire to have been heralded by that of 1456. When the comet of 837 appeared, Louis I., son of Charlemagne, who dabbled in astronomy, looked upon it as the presage of his death, and, sinking into a state of deep melancholy, did not survive it more than two years. A comet, known as Halley's comet, appeared in 1066, when William the Conqueror invaded England, and it was worked into the Bayeux tapestry by Queen Matilda. The comet of 590 was held responsible for a singular epidemic, which caused the death of people by making them sneeze to excess.

M. Babinet says: "Seneca combated the superstitious ideas of his predecessors and contemporaries, maintaining that comets moved in fixed courses, and that posterity would be unable to comprehend that so patent a truth had ever been disputed." The theoretical researches of Newton and the calculations of Halley have verified the predictions of Seneca, and the return of several comets, following as they do, regular orbits, can be accurately foretold.

The comet of 1664 was expected by the vulgar to cause the death of every European sovereign, but none of them happened to die in that year, and so far from having caused misfortunes, we have to thank them for several excellent vintages, *teste* that of 1811.

IV.

There have been many remarkable comets of recent years.

Upon the 8th of January, 1862, M. Winnecke of Poulkova observed a telescopic comet from 3 to 4 minutes in diameter, and it subsequently transpired that the same comet had been discovered by Mr. Tuttle in America, nine days beforehand.

Another comet, visible to the naked eye for those who had good sight, was seen on the 2nd of July at about 10 P.M. by M. Schmidt, director of Baron Sina's observatory at Athens. This comet appeared quite suddenly, travelling in the direction of the North Pole, and reminding one in the manner of its arrival of the great comet of 1861 as it first appeared in Europe. The latter, seven weeks before becoming visible upon our continent, had been clearly seen in the southern hemisphere, by myself, amongst others, in the Isle de la Réunion.

It was visible about 7.30 P.M. in the north-east, just about the sea-line. It gave a faint light, not greater than that of a star of the third magnitude, but on the other hand its crest, pointing eastward, extended nearly 18° in length, even as seen with the naked eye.

The comet of Charles V., expected from 1856 to 1862, and which was expected to come in contact with the earth and crush it to pieces, is now forgotten, and will not be seen in our day. And when we remember the terror which its advent caused, we can scarcely be allowed to despise the credulity of our forefathers.

V.

Out of more than six hundred comets which have been observed since the birth of Christ, the orbits of nearly one-third have been calculated, but out of this number it is impossible to predict with complete precision the return of more than eight or nine. But this subject will be treated at greater length in the latter part of this chapter.

The other comets mostly accomplish their orbits in such elongated ellipses, taking into consideration their greatest dimensions, and the portions of orbits in which we perceive them are so limited, that it is scarcely possible during a single appearance to do more than ascertain the position of the plane in which they move, and the length, as well as the direction to the perihelion, that is to say, to their shortest distance from the Sun.

It is only when the orbits of two comets which have appeared at different epochs have almost the same elements that astronomers consider themselves justified in considering these comets as identical, and, consequently, in drawing a conclusion as to the nature of the orbit and the length of the revolution.

The physical appearances of these bodies undergoes so many changes from day to day—and *à priori* between two apparitions, years apart—that it is impossible to establish their identity through a resemblance in shape.

Even a resemblance of elements can only be considered a complete proof of identity when the reappearance which has been surmised from this resemblance has actually taken place. It is not until then that a comet is classed as periodic, and that the elements of its orbit can be calculated with precision.

In the case of a comet with a known rotation, an astronomer can fix the day when it will be in its perihelion, or nearest to the Sun, and the day when it will be nearest to the Earth, but it is impossible to predict when the most familiar of the comets will become visible to us, for observation has shown that their visibility is dependent not only upon distance, but on other physical circumstances to which they may be influenced in their remote course, and which we are utterly unable to calculate.

VI.

From the earliest ages of astronomy down to the invention of the telescope, only the most brilliant comets could be seen, but now scarcely a year passes without one or two being observed.

A certain number of these bodies escape observation when they traverse the sky at day-time, unless they should coincide with some such rare occurrence as an eclipse of the Sun. Seneca relates that this did happen in the year 60 B.C.

Others, again, so brilliant as to be visible at mid-day, as, for instance, the comet in the year 44 B.C., and those of 1402 and 1532.

The comets describe such elongated ellipses round the Sun that they seem to move almost in a straight line. The position of these ellipses varies very much, as the comets move in all directions.

As they vary much in their distance from the Sun they undergo extreme alternations of heat and cold.

The comet of 1680 was, when at its perihelion, only 532,000 miles from the Sun, or more than 166 times nearer to it than we are, and must therefore have received 28,000 times more heat than reaches the Earth, which is equivalent to a temperature several thousand degrees above that of molten iron. The comet of 1843 passed within 33,000 miles of the Sun, and must have had a temperature nine million times greater than that of our globe.

As a general rule, comets do not become visible to us until they reach that part of its orbit nearest to the Sun. Arriving there, the velocity of their course increases, and they soon disappear from our gaze.

Their return, on the contrary, is often delayed by several centuries, because as they recede farther from the Sun their velocity, like that of the planets, becomes progressively less.

The rapidity of the comet of 1682, as calculated by Newton, was nearly 900,000 miles an hour, and it was coming down from the most remote regions of the expanse at a right angle to the Earth's orbit.

VII.

In 1705 Halley, taking Newton's system of attraction as his basis, made calculations on the orbit of several comets. He ascertained that the comets of 1531, 1607, and 1682, were in reality one and the same, the next reappearance of which would take place in 1759, and his prediction was verified to the letter. This comet also appeared again, as he had foretold it would, in 1835, and will not be visible again until 1911. The great axis of its orbit is 3,200,000,000 miles, and its period about 76 years.

The first comet, after that of Halley, which was taken to be periodic, was that of June, 1770, discovered by Messier. This comet was ascertained by Lexell to have an orbit so much curved that it enabled him to measure the ellipse, which had a major axis not more than three times the diameter of the terrestrial orbit. This would infer a revolution of not more than five years and some months, yet this comet never reappeared. Such a discrepancy naturally excited the attention of astronomers, and it was eventually found to be due to planetary perturbations. In 1767, for instance, contiguity to Jupiter had sufficed to convert an ellipse of 50 years and a perihelion of 500,000,000 miles into the ellipse and perihelion as observed in 1770. In 1776 this comet passed during the day-time, and while it was receding afresh Jupiter affected the ellipse of 1770 to such an extent that the comet was henceforth invisible to us, as its perihelion became 350,000,000 miles, and the length of its revolution twenty years.

Messier discovered, besides this comet, sixteen others. Delambre tells us that his love of astronomy was so great that, on Montagne of Limoges observing a new comet just as he had lost his wife, Messier exclaimed: "I had discovered eleven, and now Montagne has deprived me of my twelfth." Perceiving that his friends were alluding not to the comet, but to his wife, he admitted that she was an excellent woman, but Delambre adds, perhaps with a spice of the malice which seems inherent in scientific natures, that he was still harping on Montagne's discovery.

Newton's comet has a period of about 575 years, and it has been calculated, upon tracing it back, that it must have passed near the Earth in the year 2349 B.C., the date at which Moses puts the deluge, though this comet could not have been the cause of it. Newton amply refutes the system which has been attributed to this comet, which, at its last appearance in 1680, came within 35,000 miles of the Sun.

I must point out, however, that the predictions as to the return of comets are not always absolutely accurate. Thus, Halley's comet reappeared in 1759, but some months behind time, the delay, caused by the action of some neighbouring planets, having been foretold by Clairaut, who thus triumphantly demonstrated the truth of the attraction theory, which many of the savants had refused to accept.

The beautiful comet of 1556, calculated to return in 1848, has not reappeared. A Middelburg astronomer was at infinite labour to calculate the secondary influence of the planets upon the return of this comet, and he came to the conclusion that it would be seen in 1858, but it failed to put in an appearance, nor has it as yet been seen.

The comet of September, 1853, was 70,000,000 miles from the Earth. It travelled at the rate of 400 miles a minute, 24,000 an hour, and 576,000 a day. It was, in diameter, about equal to the Earth; its tail was 4,000,000 miles in length, and about as broad as the space which separates the Earth from the Moon, viz., 240,000 miles.

VIII.

It is not impossible for a comet to come into contact with the Earth, but there are millions of probable reasons against such an occurrence. Moreover, the ingenious mechanical calculations of M. Babinet tend to prove that this shock would affect us very slightly, owing to the trifling density of the comet compared to the atmosphere. At the same time it is only right to add that many other scientific men hold a different opinion. The substance of M. Babinet's two last communications upon this subject to the French Academy of Sciences, are as follows:—

Taking the calculations of Sir John Herschel, Struve, Bessel, Admiral Smyth, and even Arago, the contrast of intensities induced him to believe that the atmospheric equivalent of a comet was so trifling that he reduced the density of those bodies almost to nothing; for it has been impossible to discover any refraction even in their nucleus. He also points out that the result arrived at is so marvellous that he should have scarcely ventured to lay it before the academy were it not directly deduced from facts and laws universally accepted.

All astronomers have found that the density of the comets is insufficient to shut out the light of the small stars, whether it be the tail or the nucleus which comes between them and us. Therefore, even if one of those bodies should come into contact with the Earth, the matter of which it is composed, almost devoid of density, would not penetrate even the atmosphere of the globe. Stars of the tenth, eleventh, and even of inferior magnitudes have been visible through the central part of comets without suffering any perceptible diminution of brightness. It is easy to explain the error of those who have proclaimed the existence of an opaque nucleus, and no better instance can be afforded for proof than Encke's well-known comet, which is sometimes visible to the naked eye and which generally appears as a round mass. In 1828 it formed a regular globe, nearly 320,000 miles in diameter, without any distinct nucleus, and Struve was able to see through it a star of the eleventh magnitude, which suffered no diminution of brilliancy.

It is a well-ascertained fact that moonlight blots out all stars below the fourth magnitude: now there are six degrees of stars between the fifth and eleventh magnitudes, and according to the law of fractions by which these classes are governed, it follows that a star which is one degree in size greater than another is $2\frac{1}{2}$ times more luminous.

It is concluded from this that a star of the fifth magnitude is about 250 times more brilliant than one of the eleventh magnitude, and that consequently the illumination of the atmosphere by the Moon is much more intense than the illumination of the cometary substance by the Sun itself, inasmuch as a comet would need to be 3,600 times more luminous than it now is to extinguish a star of the eleventh order, while the glow of the atmosphere at moonlight is sufficient to render invisible stars 250 times more brilliant. When we study the measurements of Wollaston, against which Sir John Herschel has nothing to say, the disproportion becomes still greater, the illuminating power of the full Moon appearing to be only $\frac{1}{100,000}$ that of the Sun at noon.

M. Babinet, to complete his calculations, remarks that, judging by the density of the air in the lower strata of the atmosphere and its total weight as indicated by the column of the barometer, the whole aerial stratum which constitutes the atmosphere would not be more than five miles through if its density was everywhere as great as the air upon the surface of the Earth. He calculates that the substance of a comet has not a density greater than a 45 million milliardth part (1 divided into fraction of 45 million milliards) that of the atmosphere. The shock of so rarefied a substance would not force any particle of the comet into the most dilated parts of the extremity of our atmosphere.

Slight as the cometary substance no doubt is, it is not so to the extent that M. Babinet would make out, for, as I shall relate presently, the Earth has actually passed through the tail of one comet.

IX.

Accused of over estimating the want of density in the substance of comets, he replied:

"I will quote the language of Sir John Herschel, whose views must command general attention, and if his opinion does not carry conviction with it, I may state that I have in reserve two arguments which will prove that comets do not contain enough substance to set up a homœopathic doctor. Sir John Herschel, in his work upon the *Excessive Tenuity of Comets*, says: 'In fact, the tail of a large comet might not weigh more than a few pounds, or even ounces.' This is very plain speaking (*Outlines of Astronomy*, art. 359, 1850). In the *Revue des Deux Mondes* I have given the weight of the Earth, and there is no need to repeat it here, but the reader may rest assured that Sir John Herschel's comet is not larger, compared to the Earth, than a fly would be compared to an elephant or a whale, and even if its tail was of deadly poison it could not reach the most ephemeral of created things upon the Earth. Without quoting the saying concerning the relative levity of feathers, wind, dust, and women, it may be safely asserted that, whatever may be its truth, comets are lighter than either of the above."

X.

M. Arago says that the chances of an encounter between the comet and the Earth are almost the same as those of an encounter between two atomic grains of dust, one of which is whirled into the air at Paris, and the other in the United States. But M. Liais and several other astronomers have since ascertained that the Earth and the Moon were immersed in the tail of the Comet of 1861, and the phenomena then observed strikingly confirm the conjectures of those who maintained that the cometary substance could do no harm.

And, as M. Liais, in his book, *L'Espace Céleste* remarks, our scientific attainments permit us to ascertain the extremely rarefied state of the gaseous medium which forms the cometary appendages, and we conclude therefrom that even if these gases are deleterious the quantity with which the atmosphere would be impregnated would be too small to do us any mischief.

Just before the encounter between the Earth and the tail of the comet, M. Liais was enabled to take an observation which, combined with those made before and after, allowed ot his ascertaining as a positive fact that the passage of our globe through the tail had really taken place.

It was not until after the passage that this comet was visible in Europe, where it was seen for the first time in the evening of June 30th, 1861.

Two well known astronomers, M. Valz, of the Marseilles observatory in France, and Mr. Hind, in England, also remarked that the Earth must have passed through the tail of the comet.

During the evening of June 30th, Mr. Hind and several other observers in England had also noticed a sort of phosphorescence in the sky, with a yellow tint like that of an Aurora Borealis, and they attributed it to the cometary matter.

Baron de Prados, informed by M. Liais of what was about to occur, observed the condition of the atmosphere at Barbacene (Spain), and he remarked that the sky was very red all the time. This fact, taken in connection with what was observed in England, deserves record.

Taken altogether, the details noticed upon this occasion, show that the dangers apprehended from an encounter between the Earth and a comet are purely imaginary.

M. Petit, of the Toulouse Observatory, referring to this subject, says: "In 1783 and 1831, the Earth was covered for months together by mists, which were attributed to the passage of cometary tails. Though many persons, Arago amongst others, have declared this supposition to be erroneous, it seems evident to me—and Arago himself has admitted it in one of his works—that the planets must from time to time absorb to themselves cosmical matter, and I take this opportunity of citing a singular phenomenon which was observed on the 13th of May, 1858, at Toulouse, and other parts of the Haute-Garonne. I refer to a very strong smell of chlorine, accompanying a marked decline of light, from 2 to 7 P.M., just at the time, no doubt, when the Earth was passing through a very slender part of the asteroid annulus, with which we come into contact at that epoch of the year." *

But uncertain as the course of comets appears to be, and justified though we are in considering them as innocuous, it is well to remember that He who has given order and stability to His creation, must have imposed upon them laws which prevent the possibility of their causing confusion in the universe.

* Petit's *Treatise on Astronomy*, vol. ii. p. 107.

XI.

M. Delaunay's recent treatise upon the periodical comets, which appeared in the annual publication of the Bureau des Longitudes, furnishes me with some interesting information concerning these bodies. I may mention that he does not allude to Newton's Comet, referred to above, probably because he does not consider the date of its return sufficiently certain. We at present count eight comets which have become visible from the Earth after their return had been announced as probable.

1st. *Halley's Comet, with a period of* 76 *years.*—This comet, with a longer interval between its apparitions than any other, was discovered under very remarkable circumstances, which Lalande laid before the French Academy of Sciences in 1759, at the time when the comet reappeared in accordance with the prediction made by Halley fifty-four years previously. The fulfilment of this prediction created great satisfaction in the scientific world, and, referring to the event, Lalande says:—

"This occurrence, unparalleled of its kind, has changed our surmises into certainties, and the Academy of Sciences is delighted to announce the return of a comet, enabling us to obtain for the future a multitude of fresh data and observations. Though for a long time astronomers have counted upon the return of comets, though Newton asserted the fact, and Halley fixed the certain date of one, the event did not occur in their day. We, more fortunate, are able to compare the facts related by history, and deduce from them lessons for the future."

Lalande also remarks that Cassini was the first astronomer who attempted to calculate, by means of preceding observations, the route taken by comets, and so to ascertain the periods of their return, but he was only partially successful, because the resemblances which he saw between the comets observed by him were only apparent. The true mode of comparison was, as Halley afterwards discovered, to contrast them with the Sun, and Lalande points out that.* Halley, following the Newtonian theory, devised a convenient method of studying a comet, the parabola of which is known. He first applied this method to those comets with which he was relatively familiar, and gradually extended it to those of which less was known, until, in 1705, he had compiled a table of 24 comets, published in the *Philosophical Transactions*, No. 297.

"Comparing these 24 comets with each other, Halley remarked that those of 1531, 1607, and 1682, had orbits very similar to each other, and the resemblance, indeed, seemed to him so striking that he expected this comet would be seen again in 1758. To use his own words: 'I am very much inclined to think that the comet of 1531, observed by *Apianus*, is identical with those which reappeared in 1607 (when it was described by *Kepler* and *Longomontanus*), and in 1682 (when I myself observed it). For the elements of all three are the same, and the only marked difference in them is in the time occupied by their periodic revolution, and that may be due to various physical causes. We have an almost similar instance of this in *Saturn*, whose revolving motion is so affected by other planets, *Jupiter* more particularly, that we can never fix to a few days the duration of its periodic revolution. Therefore the motion of a comet which travels four times the distance of Saturn, would be all the more affected, espe-

* *Life of Halley. Astronomiæ Cometicæ Synopsis.*

cially as a trifling increase of its velocity may alter the shape of its orbit, and change the curvature of its ellipse to something like a parabola. I am confirmed in this view by the conviction that this comet is also identical with that which appeared in 1456. It was seen during the summer of that year following a retrograde course, and passing nearly in the same direction between the Earth and the Sun. And though no very precise observations were taken at that time, I feel certain, from a comparison of its route and the duration of its revolution, that it is the comet of 1531, 1607, and 1682, so that I can confidently predict its return in 1758. If my prediction is fulfilled, it will be impossible to doubt that the other comets also reappear in the same way.' "

XII.

As the period of its reappearance drew near, great precautions were adopted for ensuring careful observations. Clairaut conceived the idea of making a precise calculation of the attraction which Jupiter had exercised upon this comet when so close to it in 1681 and 1683, and he read a paper at the Academy of Sciences (Nov. 14th, 1758), of which I subjoin a few passages:—

"The comet which we have been expecting for over a year has excited more than the usual amount of interest amongst the public. The real lovers of science await its return, as a striking confirmation of the truth of a system which nearly all known phenomena render probable; and I undertake to show that the delay (the comet had been due over twelve months), far from weakening the theory of universal gravity, is a necessary complement of it. I will even say that the delay must be still greater, and I will endeavour to assign its limits."

He then goes on to explain what method Halley adopted to take account of the inequality in the successive periods of the comet, and that the latter roughly estimated its fresh period at 76 years, placing its probable return in 1758 or the early part of 1759.

The details appended to his prediction, though only partially worked out, were a necessary part of it; but they were omitted by those French astronomers who alluded to his theory. Moreover, impatient to see whether the prediction would be verified, people had almost forestalled the allotted period by looking for the comet before it could fairly be said to be due. Clairaut also noted the various results at which he had arrived, and stated that the revolution of the comet, subsequent to its previous appearance in 1682, would be 618 days longer than it was between 1607 and 1682. And he also added: "I consider that the comet will be in its perihelion about the middle of next April, though I make such a statement with no little diffidence, as several trifling details, of which we cannot judge approximatively, may effect an alteration of a month or so, as in the calculation of preceding periods. Moreover, as I said at the beginning of this paper, there are many unknown causes which may act upon the comet; nor can I be certain as to the absolute precision of my own calculations until they have been verified by my *confrères*."

XIII.

Lalande, referring to the same subject, says: "Clairaut asked me to give his theory a month's law, and at the expiration of that period the comet appeared, with an interval of 586 days longer than at its previous appearance in 1682. It was within 32 days of the extreme limit assigned to it, but such a period is nothing in an interval of 150 years, during which it had only been possible to take a few rough observations for nine months. To this must be added the possible effects of the attraction of the solar system, of comets as to which we know nothing, of the resistance of the ethereal matter, concerning which we can form no opinion, and of other quantities necessarily omitted from approximative calculations—all of which may conspire to hasten or retard its appearance. . . . A difference of 586 days between the revolutions of this said comet—a difference which may be due to the disturbing forces of Jupiter and Saturn—demonstrates even more strikingly than we could venture to hope the great principle of attraction, and places this law amongst those fundamental truths of physics which are as certain as the existence of the bodies producing them."

Upon the 23rd of December, 1758, the comet was perceived by a Dresden peasant called Palitsh, who forestalled all the astronomers. Thus Halley's prediction was realised, and the reappearance of the comet could be safely counted upon 75 or 76 years afterwards, viz., in 1835. Punctual to its appointed time, it was in its perihelion on the 16th of November following, Damoiseau having calculated it for the 4th, and Pontécoulant for the 13th of that month. The latter has calculated that it will be in its perihelion again on the 24th of May, 1910.*

Tracing this comet back, science, with the help of history,

* *Académie des Sciences*, vol. lviii.

has ascertained that it was observed in June, 1456, November, 1378, September and October, 1301, April and May, 1066, September, 989, March, 141, January, 66, and October of the year 12 B.C.

XIV.

2nd. *Encke's Comet, with a period of* 3 *years* 3 *months.*—This comet was discovered in 1818 by Pons, at Marseilles, and its elements calculated by Encke, the Gotha astronomer, in 1819. Its periodicity, at first calculated at 3 years and 3 months, tends to become shorter, owing to the perturbations to which it is exposed during its course through our solar system.

Poisson, in a memoir read at the Académie des Sciences, remarks: "Judged by the rapidity of its successive revolutions, this body might be considered a planet, but it is still classed with the comets because of its diverse appearances, and the fact of its not being visible to us at all points of its orbit. In order to facilitate observations of it at its return in 1822, M. Encke intended to compile a diary of its behaviour on this occasion, but as during the greater part of this revolution it was not very far off Jupiter, he was compelled to keep account of the perturbations caused by the action of the latter planet. And he found that the effect of this action would be to augment on the next occasion, by about nine days, the mean duration of the anomalistic revolution, which had taken 1,204 days, between the years 1805 and 1819. He announced that, in 1822, the comet, judging from its declinations, would only be visible in the southern hemisphere, and the event proved him to be right."*

* Annual publication of the *Bureau des Longitudes*, 1872.

From 1822 to 1871, in which latter year it was last seen, this comet has regularly appeared at intervals of about 1,200 days. (It is next due about the 15th of January, 1875.) Upon the occasion of its recent passage it was observed by M. Stephan, at Marseilles, who discovered at the same time seven new nebulæ (*Académie des Sciences,* 2nd half of 1871).

Keeping as exact an account as possible of the perturbations to which this comet is exposed from the planets, Encke arrived at the conclusion that the period of its revolution continues to shorten, a fact which would seem to indicate the presence of a resisting medium. As M. Delaunay remarks, such a medium, causing a gradual diminution in the comet's velocity, would render it more sensitive to the attraction of the Sun; its orbit would become smaller and smaller, whence would result a progressive diminution in the time which it takes to travel over this orbit.

XV.

3rd. *The comet of Biela or Gambart, with a period of 6 years.*—This comet was seen for the first time on the 27th of February, 1826, by Biela, at Josephstadt, in Bohemia, and by Gambart, ten days afterwards, at Marseilles. Clausen and Gambart made separate calculations of its elements, and ascertained the duration of its revolution, so that we are now in a position to predict the date of its reappearance.

This comet intersects the ecliptic upon which its orbit is inclosed at 12° 34′ only, so that it is very likely to come in contact with the Earth. In 1832 it passed within 20,000 miles of the terrestrial orbit, but the Earth was then at a great distance from this point, which it did not reach till a month afterwards. It has been calculated that at this distance, supposing the mass of the comet to be equal to that of the Earth, the obliquity of the ecliptic would be modified, and the length of our year considerably increased. And as we have not experienced any change, its mass cannot bear comparison with that of our globe.

It was again seen in 1846, when it presented a very remarkable phenomenon, being divided into two distinct comets, which proceeded in a parallel course, gradually separating from each other. It again appeared as a double comet in 1852, and its two halves had continued to progress, side by side, receding from each other very slowly. M. d'Arrest has calculated that on the 28th of September, 1846, the nucleus of the one part was 1,624,375 miles distant from that of the other.

This comet should have reappeared in the early part of 1866; but, though the conditions for observing it were very favourable, it was not seen. It was again due in the autumn of 1872.

A very remarkable fact, from the scientific point of view, is, that the results of manifold observations point to the probable transformation of this eagerly awaited comet into a current of meteoric bodies. This is argued by Mr. Al. Herschel in an article in the *Mondes Scientifiques* of December 12th, 1872.

Father Secchi has also communicated to the French Academy of Sciences the account of a brilliant shower of shooting-stars observed at Rome on the night of November 27th. The maximum was at about 8.30 P.M., when they were at the rate of 93 a minute. He says:—"From half-past seven to one in the morning we counted 13,892 meteors, but the actual number was much greater. The whole sky was literally on fire, and it is worthy of remark that during this phenomenon the Earth was in the node of the orbit of Biela's comet."*

It seems, then, as if this comet had undergone disruption, and that this was the cause of the great abundance of shooting-stars observed in the direction which it followed.

XVI.

4th. *Faye's Comet, with a period of 7½ years.*—This comet was discovered at the Paris Observatory on the 22nd of November, 1843, by the eminent astronomer whose name it bears. Soon afterwards, M. Goldschmidt, a pupil of Gauss, basing his computations upon observations made at Paris and Altona, calculated its elements and predicted its return in 1851. M. Le Verrier, taking into account the perturbations to which it would be subject in the course of its revolution, fixed the time of its passage in its perihelion within two days of April 3rd, 1851; and his views were singularly correct, for, reappearing at the close of 1850, it was in its perihelion at ten in the morning of April 2nd, 1851. It has since appeared three times—in 1858, 1865, and 1873. Professor Moller, of Lund (Sweden), has published the diary of this periodical comet on the occasion of its recent appearance. It was in its perihelion on the 18th of July, 1873, and gradually approached nearer to the Earth until the 10th of January, 1874.

5th. *Brorsen's Comet, with a period of 5½ years,* was discovered by Brorsen at Kiel on February 24th, 1846. As the period of its revolution was reckoned at about 5½ years,

* *Académie des Sciences* (2nd half of 1872).

it was looked for in the autumn of 1851, but it was not seen on that occasion. It was again observed on the 18th of March, 1857, and must have again been in its perihelion in 1862 and 1868; but it was only visible in the latter of those years.

6th. *D'Arrest's Comet, with a period of* 6 *years* 4 *months.*—This comet was discovered at Leipsic on the 27th of June, 1851, by the astronomer after whom it is named, and its return was announced for the close of 1857. M. Yvon Villarceau, having prepared the diary of its motions on this occasion, ascertained that it would not be visible in our hemisphere; but he forwarded his calendar to several observatories in the southern hemisphere, and Mr. M'Clear obtained a good view of it at the Cape of Good Hope. It should have been seen again in 1864; but its next appearance was in 1870, when Herr Winnecke observed it at Carlsruhe.

7th. *Tuttle's Comet, period* 13 *years* 8 *months.*—This comet was discovered at Cambridge (U.S.) by Mr. Tuttle, on the 4th of January, 1858, and was again observed by M. Borrelly at Marseilles on the night of the 12th–13th of October, 1871. It was also seen upon that occasion by Messrs. Lœwy and Tisserand at Paris, and may therefore be counted as one of the periodical comets. It has been ascertained to be the second comet of 1790, discovered at Paris by Méchain. As the interval between 1790 and 1858 comprises five revolutions of the comet, it must have returned five times (in 1803, 1817, 1830, and 1844) without being seen, and it was again due in 1871. Basing his computations upon these facts and the calendar drawn up by Hind, M. Borrelly was enabled to observe it in that year.

8th. *Winnecke's Comet, with a period of* 5½ *years,* was discovered at the Bonn Observatory on the 8th of March, 1858. Its parabolic elements bore a great resemblance to those of the third comet in 1819, discovered by Pons at Marseilles, and it was soon ascertained that they were one and the same. Since 1819 it has made seven revolutions, and it has again been seen after two fresh revolutions only three days apart from their predicted date, as Winnecke himself was enabled to announce in 1869. It was again due in the course of 1874.

XVII.

I will conclude this chapter with M. Delaunay's summary of the knowledge which we at present possess about comets generally. He says:—

"Comets occupy, so to speak, an intermediate position, belonging partly to the stellar, partly to the planetary system. They are small and irresoluble nebulæ which travel in space, and which, coming within the sphere of the Sun's attraction, approach that body at an increasing velocity, revolve around it at a varying distance from its surface, and again move off towards other regions of the sky, losing their velocity as they recede. If the Sun were not attended by planets, all the comets which we see would move in conformity with the principles enunciated, except in the rare event of a comet coming directly in the Sun's course, and being lost in its mass. The presence of the planets which circulate round the Sun, and which the comets skirt in their motion towards it, often leads to important modifications in the course of these wandering nebulæ. The attraction exercised by a planet upon a comet which passes close to it may effect a great change in the size and direction of the latter, making the comet's orbit round the Sun very different from what it was before. This orbit may become elliptical, in which case the comet has a motion analogous to that of the planets, being incorporated, so to speak, in the solar system. It then becomes a periodical comet, reappearing at regular intervals whenever it is near enough at its perihelion to be visible from the Earth. But, just as a comet coming from the depths of space may be made periodical by the action of certain planets, so the motion of a periodical comet may undergo such an entire change in its passage near a planet, that it will cease to be periodical, and recede indefinitely until it falls into the sphere of attraction of some other sun. Thus we see how the nature of comets varies." *

* *Rapport sur les Progrès de l'Astronomie*, p. 32.

CHAPTER XV.

SHOOTING-STARS, BOLIDES, METEORITES, ETC.

These phenomena alluded to by Homer, Ossian, Milton—Phenomena which must not be confounded with each other—Meteorites and their subdivisions—Gaseous or pulverulent matters reaching the terrestrial atmosphere from the planetary regions—Showers of Sahara sand observed at a great distance from the desert—Apparitions, motion, number, shape, composition, and weight of meteorites—History of principal meteorites—Meteorites of the rivers Ægos-Potamos and Abydos—Cybele and the Sun worshipped in the form of meteorites—Extraordinary bolides, as related by Plutarch—Meteorites in the Paris Exhibition of 1867—Modern *savants* and the meteorites; the pertinacity of M. Chladni—Shower of aerolites in 1803, which were observed by M. Biot—Hypotheses suggested in explanation of these phenomena—Are meteorites found in the atmosphere?—Are they asteroids or small planets?—The Moon, a troublesome neighbour—Analogy between meteorites and comets—Has the Biela comet been transformed into meteorites?—Periodical apparitions—Radiant points—Periodic and sporadic shooting-stars—Days and months when shooting-stars are most numerous—The influence of the precession upon their apparition—Shooting-stars and the Chinese—Meteoric currents—Shooting-stars subject to the general laws of the universe.

I.

The name of *shooting-star* is given to bodies which seem on fire, and move through the sky with enormous rapidity. They are commonly called *bolides,* and also *aerolites, meteorites,* &c.

It is evident that the brilliant phenomena of shooting-stars have been known from the earliest times, as various writers not only employ them in metaphors, but give an accurate account of them. Homer, describing the descent of Minerva from the heights of Olympus, to break off the truce between the Greeks and the Trojans, says:—"Like a star, shot by the son of crafty Saturn, as a warning to sailors or to a great army, which glitters and darts forth many scintillations, so did Minerva, speeding to the Earth, throw herself into the arena." *

Ossian makes the bereaved Fergus exclaim: "And thou too, Morna, loveliest of maidens, thou sleepest thy last sleep on the hollow rock. Thou hast been precipitated into the darkness like a shooting-star which is buried in the deserts of the sky, and the passing light of which is regretted by the solitary traveller." †

Milton also, in the Fourth Book of "Paradise Lost," compares Uriël to a shooting-star:—

> "Thither came Uriël, gliding through the even
> On a sunbeam, swift as a shooting-star
> In autumn thwarts the night, when vapours fir'd
> Impress the air, and shews the mariner
> From what point of his compass to beware
> Impetuous winds."

II.

Those who are not versed in the study of meteorology are inclined to think that all *shooting-stars* are of this nature and origin. It was to prevent any error of this kind that, when the denomination of *bolide* was given to a meteor recently observed, M. Élie de Beaumont pointed out that, in studying these phenomena, it is important not to forget that a bolide, from the derivation of the word, is a sort of natural projectile, and that about the year 1820 it became apparent that most of the shooting-stars answered to this

* *Iliad*, Book iv.
† Ossian, Book i.

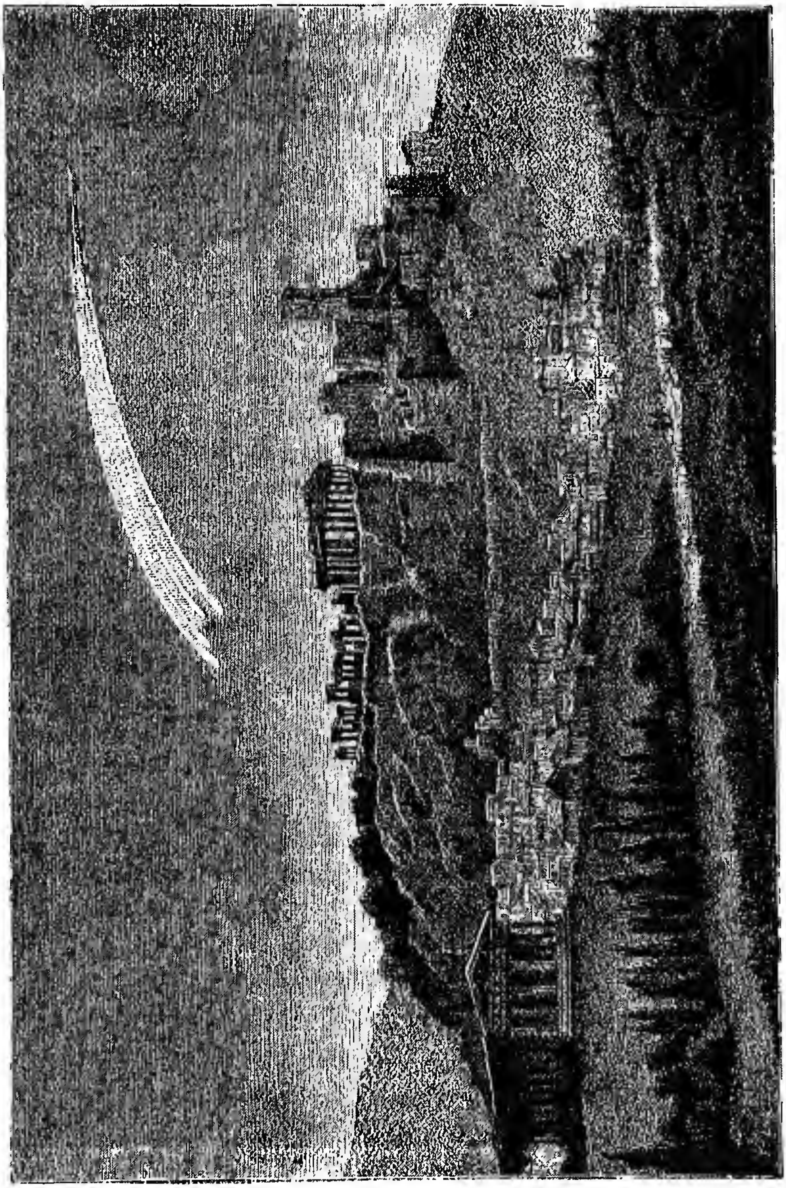

Fig. 56.—Bolide in fusion observed over Athens.

description. But, at the same time, there is nothing to show that luminous points or discs of a different kind do not from time to time appear in the sky. Before looking upon the shooting-stars as being generally very small planetary bodies, he would suggest an examination as to whether they might not result from the conflagration of masses of vapour condensed in certain parts of the atmosphere. The existence of *wills-o'-the-wisp, thunderbolts, phosphorescent clouds,* and other unknown apparitions of the kind, proves how careful we must be in our denomination of these phenomena (*Académie des Sciences,* 1871). Thus, we must not set down indiscriminately as bolides or shooting-stars all the luminous and fugitive points which traverse space, as is too often done.

III.

The bodies which reach our atmosphere from the planetary region, and which are comprised in the generic term *meteorites,* have been divided into two classes—the *irons* or mesosiderites, and the *stones* or *lithosiderites,* though of late years a third division, intermediate between the other two, that of *siderolites,* has been introduced by certain astronomers.

It has also been ascertained that, accompanying the solid masses, or at least having the same origin, certain gaseous or pulverulent matters reach our atmosphere. In a memoir by M. Baumhauer, presented to the Académie des Sciences by M. Ch. Sainte-Claire Deville, there are some interesting heads of information. He maintains that not only solid bodies, but also mists of uncondensed matter, penetrate to our atmosphere, and that, as the meteoric stones are partially and the meteoric masses of iron almost entirely composed of iron and nickel, so it may be that the meteoric mists also contain a considerable proportion of magnetic metals. M. Baumhauer considers that the main cause of auroræ boreales is the magnetic action of these mists upon the Earth.

He goes on to say that there are grounds for believing that the higher regions of the atmosphere contain metallic particles, in proof of which he cites the case of hailstones with a metallic nucleus, as observed by Eversman at Sterlitamack, in Russia. These stones contained sulphate of iron crystals; while in some hailstones which fell at Majo (Spain) on the 21st of June, 1821, M. Pictet discovered iron. M. Baumhauer attaches special importance to the hailstones picked up at Padua on the 26th of August, 1834, which, of an ashy-gray colour, were found by Cozari to consist of various-sized grains, the largest of which were attracted by a loadstone, and were composed of iron and nickel. He adds that the identity of this matter with that composing aerolites is beyond doubt, and that M. Quételet, whose death in February last deprived Europe of one of her greatest astronomers, has remarked that the epoch when auroræ boreales are most frequent coincides with the period of the asteroids. Without asserting that his theory as to the auroræ boreales is positively true, he considers it worth investigation.*

IV.

Tarry, in a letter to the Académie des Sciences (1st half of 1872), concerning the periodicity of the atmospheric phenomenon of sand-showers observed in the south of Europe,

* *Académie des Sciences*, 1872.

endeavours to prove that the three showers of December 26th, 1870, June 27th, 1871, and March 10th, 1872, were due to cyclones which, after traversing the continent from north-west to south-east, became subject to a retrograde motion when they reached the tropical regions. The conditions of these phenomena are now so well known that their arrival can be predicted several days beforehand. In proof of this, he adduces the warning which he issued on February 27th, 1872, to several of the observatories in the south of Europe of a sand-shower which would take place in the early part of March. It occurred, as he afterwards learnt from Rome and Palermo, on the 10th and 11th of that month. All seafaring men must have remarked that the sands from the deserts are carried out a great distance to sea, and I myself noticed, at two hundred leagues from the African coast, some very fine dust of a reddish colour which had remained attached to the sails of the vessel in which I was a passenger.

M. Daubrée, of the Académie des Sciences, confirmed this fact in a memoir which he received from the French Consul at Sainte-Croix, in Teneriffe, who forwarded with it a sample of the sand, which fell like rain in the western part of the archipelago of the Canary Islands on the 7th of February, 1863. The vessels at anchor there were coated with it, and the peak of Teneriffe, though covered with snow, seemed of a yellow colour after the shower. The grains of this sand were so fine as to be almost impalpable, and, with this exception, it was exactly like the sand of Sahara, notably that part of the desert near Biskra, its mineral components being the same down to the very *débris* of shells which are to be found all over the African desert. There can be no doubt that it had, in fact, been blown there, though Sahara is nearly 200 miles away, and it was probably raised by a waterspout to a height of more than 12,000 feet above the level of the sea, whence it would reach the zone of the atmospheric counter-current.

I may add, in explanation, that the sand may be conveyed upon the sails of a vessel without any violent winds, as the deposit may be effected by the slightest possible breeze. Moreover, we find an analogy to this phenomenon in the ejaculation of volcanic ashes, as in the year 472 the ashes of Vesuvius were projected as far as Constantinople, which is 700 miles distant.

V.

At the same time, I am disinclined to believe that all sorts of dust, especially the metallic atoms suspended in the atmosphere, have a terrestrial origin; and I rather agree with the views put forward by M. Daubrée in his notice on their classification in the French Museum of Meteorites. He says: "Though solid meteorites alone reach the surface of the soil, it is very probable that gaseous or liquid matter accompanying the solids, or at all events having a common origin, penetrate into the atmosphere." Our knowledge concerning these extra-terrestrial fluids is, however, too limited to allow of our classifying them together.

Moreover, amongst the solid meteorites, many have been known to fall with the same accompaniment of light and report, not in a coherent mass, like ordinary meteors, but in the shape of dust. As these meteoric particles have not been sufficiently examined and distinguished from the dust proper to the Earth, and as their nature may also be modified through their combustion in the air, I am unwilling to attempt any explanation of them.*

VI.

The speed of these meteors has been said to attain 36 miles a second, double that of the Earth's motion round the Sun.

Supposing that it is only half as much, even then it would be greater than that of all the principal planets, the Earth alone excepted.

There is, however, a diversity of opinion upon this subject, and M. Daubrée tells us that the Orgueil meteorite travelled at the rate of 15 miles a second, and that the speed of others was half as much again.

It has been ascertained that if shooting-stars catch fire in our atmosphere, they do not originate in it—that they come from the regions beyond it, and their direction generally seems diametrically opposite to that of the Earth in its orbit.

Their number is sometimes prodigious, and, during the great shower of shooting-stars witnessed in America upon the night of November 12-13, they succeeded each other at such rapid intervals, that it was impossible to count them, though the lowest estimate put them at hundreds of thousands.

They were seen all along the east coast of America, from the Gulf of Mexico to Halifax, from 9 P.M. until sunrise, and, at some points, until 8 A.M.

During their course through space, the meteorites emit numerous sparks and leave a brilliant train behind them. They often disappear without causing any secondary pheno-

* *Académie des Sciences* (July 8th, 1872).

mena; but sometimes they are accompanied by detonations as loud as the report of a cannon, which are in turn followed by the whistling sound of a projectile cleaving the air. These projectiles, as they in fact are, are nearly all identical both in regard to their physical components and their size.

The results of several hundred analytic examinations go to prove that meteorites do not contain any elementary substance foreign to our globe. The elements which they contain number, so far as is at present known, twenty-two, and they are, taking them in the order of their predominance, as follows: *iron, magnesium, silicon, oxygen, nickel, cobalt, chromium, manganese, titanium, tin, copper, aluminium, potassium, sodium, calcium, arsenic, phosphorus, nitrogen, chlorine, carbon,* and *hydrogen.* It is very remarkable that the three bodies which predominate in the general composition of these meteorites, the *iron,* the *silicon,* and the *oxygen,* are those which preponderate in our globe.* It is also worthy of notice that the *iron* and the *silicon* are in a metallic state, which is not the case with many of the mineral aggregations upon the surface of the Earth.

As a general rule, the aerolites are of a very uniform shape; their numerous angles are often rendered obtuse by the process of fusion, and their surface is covered with a kind of black metallic enamel which is rarely more than a millimètre (·03937 of an inch) thick. At the moment of their descent they are very hot, and they range in weight from a few grains to several hundredweight. The aerolite seen by Pallas in Siberia was estimated at nearly 16 cwt., and another that fell in Brazil, though not more than four cubic feet, weighed 14 cwt. It is said that one found upon

* Daubrée's *Étude récente sur les Météorites,* p. 53

the banks of the Plata was nearly 14 tons weight. In the neighbourhood of Orgueil (France) there was a fall of these stones at about sixty different places, all within an oval less than 13 miles long, and at Laigle some 3,000 fell within an even smaller compass.

VII.

M. J. Schmidt made a very remarkable observation of a bolide in a state of fusion composed of two main fragments with a brilliant green tint. The larger of the two fragments followed the other, but there was little difference in their size; each of them had a red tail, with the limit separating it from the other clearly defined; and they were also succeeded by smaller luminous bodies (each with its red trail) irregularly distributed like sparks along the extent of the tail of the main meteor, which faded away to nothing at about 1 degree above the horizon. At this latter point it appeared to consist of four or five fragments dirty red in hue (see fig. 56, p. 319).

Father Secchi gives an interesting account of a bolide seen near Rome upon the morning of August 31st, 1872, which bore great analogy to a comet. At about 5.15 A.M. a globe of bright flame slightly tinged with red appeared upon the S.S.W. horizon, travelling N.N.E. Moving slowly at first, its velocity soon increased, and it left in its track a luminous train like the smoke of a railway locomotive, or of a cloud when illuminated by the Sun, which, however, had not risen. When it reached its culminating point, E.N.E. of Rome, the flame expanded to the shape of a cone, round at its base, and, shedding a bright light, disappeared, darting the while small streaks of fire. From two to four minutes afterwards, according to the position of the observer, a detonation was heard loud enough to shake many of the houses and break the glass in their windows. The report, less sharp than that of a thunder-clap, resembled rather the blasting of a mine or the explosion of a powder-magazine. It was followed by a rolling sound like that of file-firing when succeeded by two loud artillery reports. Fragments of black ferruginous stones were afterwards picked up. The observation of this bolide is a matter of great importance, for it appears to have been seen in the dark like a comet approaching the Earth, and at the moment of its apparition it seemed almost as large as the Moon.*

Plutarch alludes to a very similar bolide which appeared in his day. Lucullus was in command of the Roman army against Mithridates, and "the battle was about to begin, when suddenly, without premonitory signs, the heavens opened, and a large burning body, in the shape of a barrel and in colour like incandescent silver, fell to the ground between the two camps. The two armies, equally terrified by this prodigy, separated without fighting. This phenomenon is said to have occurred at Otryges, in Phrygia." †

A remarkable bolide was observed by M. Silbermann upon the 11th of June, 1867, soon after sunset, travelling E.N.E. at a gradually diminished velocity. When it reached a certain point very distant from the zenith, it suddenly vanished from sight, and farther on in the same trajectory, at a distance between two and three times the diameter of the Moon, the bolide manifested its presence by a sudden explosion, accompanied by a brilliant green flash of light. Analogous phenomena have often been remarked, one of which is reproduced in Chromo-lithograph No. 9.

* *Académie des Sciences* (2nd half of 1872).

† Plutarch's *Life of Lucullus*.

VIII.

Many meteorites were shown in the Paris Exhibition of 1867. The St. Petersburg Academy of Sciences sent a series of cardboard models of the Russian meteorites, including that seen by Pallas, and afterwards presented them to the Paris Museum of Natural History. The Madrid Academy of Sciences also sent a meteorite of stony composition, which fell in the province of Murcia in 1858, and which was remarkable from the fact of its being in the shape of a square parallelopiped. A metallic meteorite, with curious cavities upon its surface, formed part of the Chilian collection, and it also has been presented to the Paris Museum of Natural History.*

Aerolites have been known in all ages. Anaxagoras supposed that they fell from the Sun, which he looked upon as itself an immense aerolite. In his day, a black stone, as large as a chariot, fell near the river Ægospotamos, in Thrace, and is the first of these phenomena mentioned in history. This stone was still visible during the reign of Vespasian. Others were afterwards found in the Abydos Gymnasium, and at Canondria in Macedon. Pliny states that he himself saw one fall in the country of the Vocontii (Narbonnese Gaul). Cybele was worshipped by the Galatians in the shape of a stone fallen from the sky, and at Emesa in Syria the Sun was worshipped in the like form.

It is natural to inquire whence proceed these bodies which from the most remote ages have fallen upon the surface of the globe in such large numbers.

M. Daubrée, in his monograph upon the meteorites already

* Daubrée's Report of the International Jury, Paris, 1867.

mentioned, remarks: "When we reflect upon the quantity which reach the Earth every year, the natural induction would be that many fell during the enormous intervals of time when the stratified soils were in process of formation at the bottom of the ocean, where they would have lodged. Yet the most minute research has failed to discover any trace of such bodies.

"This fact, remarkable though it seems, may perhaps be explained (as the result of my recent experiments would indicate) by the rapidity with which these stones disappear, owing to their oxydation when exposed to the action of water." *

Upon my return from the Indian Ocean, a magnificent bolide, the apparent diameter of which was nearly equal to that of the Moon, fell near our vessel (see fig. 57). M. Daubrée has also pointed out that stones of a certain volume often penetrate deep into the ground; for instance, one of those picked up at Aumale (Algeria) was imbedded more than a foot in a block of hard chalk. This shows that many meteorites may become lost to view.

IX.

For a long time, philosophers, being unable to explain the phenomenon of aerolites, refused to believe in their existence. It was not until 1794 that a certain M. Chladni ventured to adopt the popular view, superstitious as it was then thought, and to prove that, unlike many other superstitions, it was not without foundation. And when, upon the 26th of April, 1803, a shower of very remarkable stones fell during daylight at Laigle, a small town in Normandy,

* *Étude récente sur les Météorites*, p. 8.

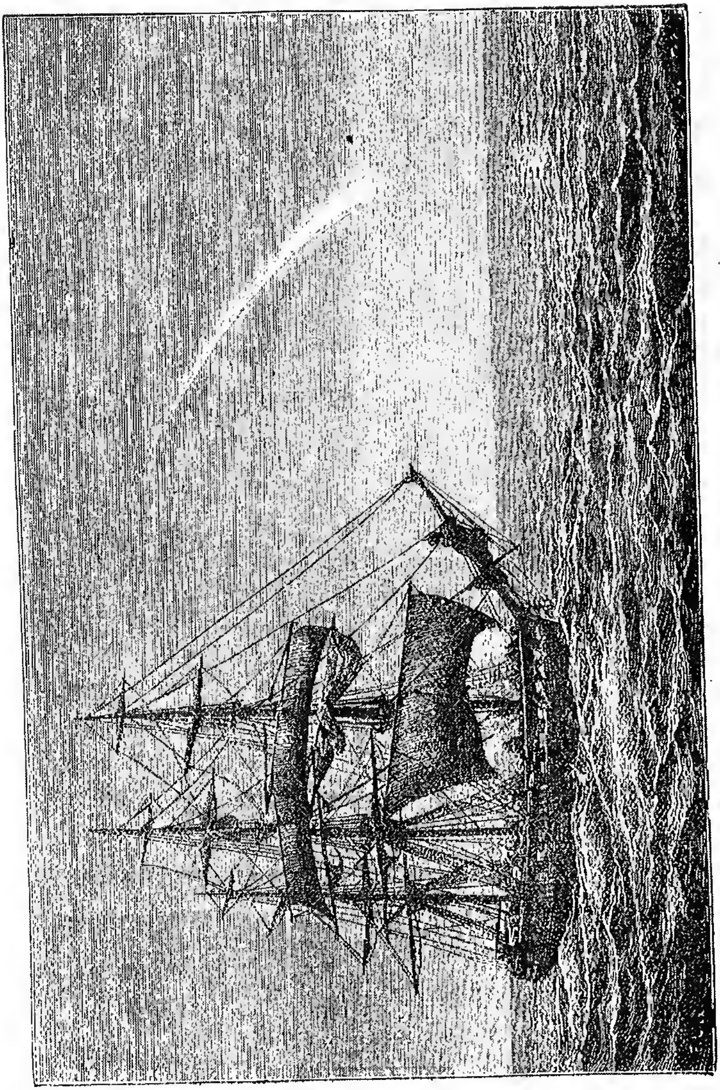

Fig. 57.—The fall of a bolide at sea.

the Institute appointed a commission to visit the spot, and their report left no doubt as to the reality of aerolites.

Biot was nominated by the Académie des Sciences to go and study the nature of this phenomenon, which seemed of such questionable authenticity even to this body, familiar as it is with science, that many of the members were averse to taking the matter up, for fear of compromising their dignity. M. de Laplace, however, overruled their objections, and Biot's researches showed that he was right.

The following hypotheses were put forward in explanation of the phenomena:—1st. The aerolites were supposed to be, like hail or rain, actual meteors formed in the atmosphere by aggregation.

Simple at first sight, this hypothesis eventually proved untenable. As a matter of fact, the elements which constitute aerolites are not found in the atmosphere; and, moreover, these elements would have to exist there in a gaseous state, and in quantities large enough to form masses weighing several hundredweight or thousands of stones of different sizes. If the aerolites formed in the atmosphere they would be subject to the laws of gravity, and would fall in a straight line, which is so far from being the case, that they have a horizontal decline apparently more pronounced than that of our planet in its motion round the Sun.

2nd. Laplace thought that the aerolites might originate in eruptions of lunar volcanoes. Lichtemberg had already declared that "the Moon is a troublesome neighbour, who salutes the Earth by throwing stones at it." As the Moon is not surrounded by a resisting atmosphere, it is possible that a stone might be ejected by one of its volcanoes with sufficient force to get beyond the sphere of lunar attraction and reach that of the Earth's attraction. This would occur if the stone was projected at a velocity $5\frac{1}{2}$ times greater than that of a cannon-ball.

This hypothesis explains the oblique direction which the aerolites follow, for, once beyond the limit of lunar attraction, the stone becomes a satellite of the Earth, and, owing to the perturbations to which it is subject, finally falls to the surface.

3rd. Chladni argued that the aerolites were fragments of planets, or even themselves diminutive planets, which, circulating in space, had entered the terrestrial atmosphere, and, gradually being deprived of their velocity owing to the resistance of the air, finally fell to the surface of the Earth.

This hypothesis, which converts them into *asteroids* or small planets, a name formerly bestowed upon Ceres, Pallas, Juno, and Vesta, circulating in milliards round the Sun, and only becoming visible to us when they penetrate our atmosphere and are set on fire there, would explain most of the circumstances which precede and accompany their fall.

M. S. Meunier, who has devoted special attention to the study of meteorites, after laying down the principles which he has evolved, says: "Putting all hypotheses on one side, it appears that the meteorites are derived from some planet, now in a state of disaggregation, of which they form the *débris*." *

X.

It is only very recently that astronomers have been so far able to trace their true origin as to permit of their discarding

* *Académie des Sciences* (2nd half of 1870).

the ancient theories, which were merely based upon supposition. It has been found that the Earth rushes upon its rapid course like a vast cannon-ball amidst moving clusters and rings of bullets circulating everlastingly in fixed ellipses. These rings are regular rivers without beginning or end, which pour along their bed in celestial projectiles, intersecting at several points the invisible route which the Earth follows round the Sun.

The Earth, in its passage through them, is struck by thousands of the small planets which drop on to its surface, and its attractive force drags a great number more of them in its train, causing them to revolve around it for some time, like so many imperceptible moons, until they, too, fall to its surface in the shape of shooting-stars so-called.

These phenomena have an imposing character which is calculated to excite awe in the minds of those who witness them for the first time. But it is still more marvellous to reflect that our knowledge of the laws which regulate the planetary system enables us to fathom their origin and the way in which they have been attracted to us.

The extraordinary discovery of two periodic comets, in close connexion with the showers of shooting-stars in August and November, has exhibited the question of meteors in a new light. Astronomers generally agreed in considering the shooting-stars as forming part of the continuous rings or clusters of cosmical matter which circulate around the Sun, until M. Schiaparelli conceived the idea of ascertaining the parabolic elements of the shower of August the 11th, just as if it was a comet coming from the remote regions of space. He concluded that the shower was unconnected with the solar system; and M. Delaunay says that his researches, for which he was awarded the Lalande medal, have opened a new path which will lead astronomers to the discovery of the most important facts concerning the constitution of the universe. Soon afterwards, M. Le Verrier, computing the retrograde motion of the November shooting-stars, arrived at the same conclusions as M. Schiaparelli. Thus, they both assert that shooting-stars originate in the disruption of vast masses of cosmical matter which penetrate into our system, and which afterwards undergo total disaggregation under the disturbing action of the Sun or one of the large planets. The result of this would be a dispersion of these matters along the orbit described by the primitive centre of gravity of the mass, a dispersion which would eventually lead to the constitution of a regular ring.

XI.

Two discoveries, made almost simultaneously by Messrs. Schiaparelli and Peters in regard to the two orbits alluded to, created great surprise in the scientific world. A remarkable coincidence was at once arrived at—for these orbits were found to be in every particular identical with the orbits, recently calculated by Oppölzer, of the great comet of 1862 and of the first comet of 1866. And it is inferred that these two cosmical masses both contained a comet when they penetrated into our system, comets which escaped the complete disaggregation of the primitive masses while continuing to describe the same orbit as the matter which had been broken up into fragments. Chladni suspected, so early as 1819, that there was a connection between comets and shooting-stars, and Mr. Newton demonstrated in 1866 the great eccentricities of their known orbits; so Delaunay is no doubt justified in asserting that "shooting-stars must be henceforth classed as small comets moving through space in clusters." *

It may also be worth while to append a very strange fact of recent occurrence. The observations of astronomers have made it almost certain that Biela's comet, which has been so long expected to appear, has been transformed into a current of meteoric bodies (see M. Herschel's article in the *Mondes Scientifiques*, December, 1872).

Father Secchi also mentions a brilliant apparition of shooting-stars on the 27th of November, 1872, the whole sky seeming to be on fire, while it was remarkable that during the phenomenon the Earth was in the node of the orbit of the comet (2nd half of *Académie des Sciences*, 1872).

Biela or Gambart's comet was known to have a period of 6¾ years, intersecting the ecliptic, to which its orbit has an inclination of only 12 degrees 34, thereby rendering its encounter with the Earth very possible. It should have reappeared in the autumn of 1872, and, as I have said, astronomers are inclined to believe that it has been broken up into the extraordinary numbers of shooting-stars observed in the direction where it would have appeared.

At the same time, our actual knowledge does not enable us to draw any rigorous conclusion as to whether the matter composing comets and the clusters of shooting-stars is identical or different.

XII.

M. Le Verrier, in his communication to the Académie des Sciences referred to above, says that Mr. Newton of

* *Rapport sur les Progrès de l'Astronomie*, p. 36.

Newhaven (U.S.), alluding to the showers of shooting-stars since A.D. 902, has fixed the duration of a period of the November phenomenon at 33¼ years.

The discontinuity of the phenomenon shows that it is not due to the presence of a ring of asteroids encountered by the Earth, but to the existence of a cluster of asteroids moving in closely adjacent orbits, and intersecting the ecliptic, about the 13th of November.

The cluster in question might be of a much older date than our system, but there is reason to suppose that it is of recent origin.

It is a striking fact that the November swarm reaches as far as the orbit of Uranus, and even a little beyond it, all the more so because these orbits intersect each other at a point situated in the rear of the swarm's passage to its aphelion and above the plane of the ecliptic. Now, Uranus and the swarm could not have been both at this point simultaneously—that is to say, close to the node of the orbit—earlier than the year 126; but in the beginning of that year the cluster might have been close to Uranus, when the action of that planet would have probably forced it into the orbit which it now occupies, just as Jupiter provided us with the comet of 1770.

Thus all the observed phenomena may be explained by the presence of a globular cluster, forced by Uranus in the year 126 into the orbit assigned to the cluster in which our November asteroids now originate. The periodic stars of August 10th, which, as the phenomenon recurs every year, must be emitted by a regular ring, also admit of a similar explanation. The only difference is that the phenomenon has lasted longer; the ring has had the time to form, and does not lend itself to so complete a study as the November shower, while the annual continuity of the phenomenon prevents us from calculating the period very accurately.

The researches of Schiaparelli and Le Verrier serve, however, to throw great light upon the theory of shooting-stars, and place it beyond mere conjecture.

XIII.

M. Faye maintains that the meteoric rings of April, August, and November, the periodicity of which does not admit of doubt, are, like the terrestrial orbit, almost circular; and that, besides these three great rings, there are a vast number of asteroids disseminated in all directions, which, in addition to being seen at the main periods of shooting-stars, form the contingent of the shooting-stars seen at other times of the year. It seems that the majority of these stars are in the ecliptic region, and move in clusters. The two main meteoric rings of August and November are henceforward clearly characterised both in respect to their secular stability, the position and motion of their nodes, the date of their regular returns, and the maximum period between their apparitions (*Académie des Sciences,* 2nd half of 1871).

M. Le Verrier, alluding to the apparition of the 12th–14th November, says that the shower gradually lessens, and that the part of the sky which it traverses is very irregularly divided. Thus, on the 12th, 107 shooting-stars were seen at Brest and not one at Toulon, though the weather was equally fine in both places. Upon the 13th the number did not seem to increase at the western stations, but at the Barcelonnette Normal School 284 were counted, and upon the 14th, at the same place, 544. At Alexandria, Genoa, Milan, &c., when the sky became clear, a large number were observed. Denza was of opinion that the meteoric current passed off in the night of the 14th to the 15th, but that the radiant point was perhaps a trifle displaced; to which M. Le Verrier replied that there was no displacement of the radiating point or focus from day to day, but that there are *several* radiating points which predominate in succession.*

Father Secchi in his account mentions that, from what he observed of the shooting-stars on August 10th, 1827, these stars must be derived from at least three different points—one in the direction of Cassiopea, another in that of Perseus, and the third from the constellation of Camelopardalis (*Académie des Sciences*, 1869).

XIV.

Thus we have the sporadic shooting-stars which appear all through the year in every imaginable direction at the rate of 10 or 11 an hour, and the periodic shooting-stars which have appeared in clusters about the 9th–11th of August with great regularity since 1842. Lastly, there are the periodic November stars, the maxima of which vary very much from year to year.

It is unnecessary to take the *precession* into account for a calculation of a few years; but, in tracing back the shooting-stars during previous centuries, it must be included in the reckoning. If the phenomenon of August 10th, for instance, corresponds to the same point in the terrestrial orbit, its date would diminish by a day in every period of $71\frac{3}{5}$ years, counting back; so that 716 years ago the phenomenon must have

* *Academie des Sciences* (2nd half of 1871).

occurred about the 31st of July or ten days sooner. The Chinese annals allude to an apparition on the 5th of August, 1451, while our calculations indicate that it should have been the 4th. Thus, in the course of ages, the phenomenon undergoes a change in date, being two weeks earlier every thousand years, just like the arrival of the Earth at a fixed point of the ecliptic. The only conclusion to be drawn from this is, that the ring of asteroids intersects the terrestrial orbit at an almost invariable point, which may be now estimated as 318 degrees longitude, and that such has been the case for the last thousand years. The varying intensity recently observed in these phenomena does not militate against this supposition; for, admitting the period of variation to be 20 years, the phenomenon would be explained by the unequal density of the ring combined with the difference of $\frac{1}{20}$ between the time of its rotation and the length of the year.

This is not so with the November swarm. The celebrated showers of 1799 and 1833 certainly took place from the 12th to the 13th; but at other times they have varied between the 26th of October and the 16th of November, and have now almost totally disappeared.

XV.

Silbermann, of the Collège de France, has devoted special attention to the shooting-stars and collateral phenomena, and he attributes to their influence most of the important meteorological occurrences. It is impossible for me to relate at length the fruitful results of his researches, and I must be content to note a few of the most important.

He remarks that, if the shooting-stars travel from E. to W., the thermometer tends to rise, the barometer begins to fall, and the compass remains stationary. If their course is from W. to E., the thermometer has a tendency to fall, the barometer to rise, and the compass remains stationary. If they are travelling from N. to S., the thermometer and barometer both remain stationary, and the compass has a tendency to point eastward. When their direction is intermediate to that of any of the points mentioned, the result is relatively identical. When some shooting-stars are moving from E. to W. and others from W. to E., the compass does not undergo any deviation. The temperature increases in proportion to the number of shooting-stars travelling in a direction opposed to the rotation of the Earth, for in that case their velocity is lessened by the attracting force of the Earth, while, moving more slowly through space, their own heat is increased. The number of radiant points which have been hitherto computed is 95, and they are indicated by the names of the constellations from which they appear to radiate. Amongst the principal ones are the *Leonides* and the *Lyrides* as represented in the accompanying chromolithograph. The *Leonides* have been observed on one or two occasions to be shaded with a faint auroral tint. Amongst the Leonides are two bolides seen by M. Silbermann soon after midnight on the 13th–14th November, 1866. In a space of 60 degrees, they revolved no less than eight times around each other.

M. Silbermann is of opinion that "the mass of the Perseides is much larger than that of the Leonides, inasmuch as it was capable of producing the aurora borealis of August, 1869, while the Leonides, though far more brilliant, would not then have given rise to a very visible aurora. Nevertheless, this might not have been the shower of shooting-stars seen in November, 1866, for the colour of these stars seemed to be the whiter in proportion to the altitude of the sky through which they moved, while they were yellow, orange, blue, red, and green, according as their trajectory was nearer to the N.W., at from 20 to 30 degrees above the horizon. These facts imply the existence of atmospheric tides, which would be rendered visible by the rapid ascent of vapour charged with electricity and its transformation into light." *

It is needless to remark that all these facts relative to shooting-stars come within the law of universal gravity, of which they serve to illustrate the truth.

XVI.

The most useful observations of shooting-stars have been taken by M. Coulvier Gravier and his son-in-law, M. Chapelas, and their contributions to the Académie des Sciences would, if put together, form several large volumes. Amongst other communications from this source, is a paper by M. Chapelas concerning the direction taken by shooting-stars, based on observations, 39,771 in number, extending over twenty years (1848–1868). His conclusion is that the number of these meteors increases from spring to summer, and diminishes from autumn to winter. If shooting-stars are examined without regard to their apparent diameter, it will be found that their mean direction is always southerly, no matter at what epoch of the year. If their mean direction is calculated in accordance with their size and with the two principal epochs of the year, a result will be arrived at from which this important principle may be deduced, viz.,

* *Académie des Sciences*, Feb. 19th, 1872.

that there are two kinds of meteoric currents—one the direction of which is constant, another the direction of which varies with the time of year; the first predominating in the upper strata of the atmosphere, the second having its centre of action in a region nearer to the Earth. And he remarks, in conclusion, that the indubitable connection between the atmospheric currents and the direction of shooting-stars may lead to useful discoveries (*Académie des Sciences,* 2nd half of 1872).

Thus we see that the study of this branch of astronomy is anything but complete. Still, we know enough to affirm that the shooting-stars, in all their evolutions, are in harmony with the laws of the universe.

CHAPTER XVI.

THE DIVISION OF TIME.

Division of time; the day, week, and month—The year; that of the Egyptians and of the Chaldæans—The Olympiads—The Roman year—Months added by Numa—Curious passage from Plutarch; different lengths of the years—The Julian year—The Gregorian calendar—Reckonings of the Sun and Moon amongst the Mexicans—Russian and Greek dates—The solar cycle—The lunar cycle or golden number—Period called *Saros* by the ancients—The epacts—Composition of the calendar—The calendar and meridian—The absolute time and the mean time—Precession of the equinoxes—Great year, or the world's year.

I.

THE ancients based their division of time upon the motions of the most visible of the celestial bodies, such as the Sun and the Moon.

The perpetual alternations of light and darkness caused by the Earth's rotation upon itself naturally determined the length of that portion of time called *day*. The Athenians regulated their horal system from sunset to sunset; the Babylonians, from sunrise to sunrise; the Egyptian and Roman priests, from midnight to midnight.

The apparent revolution of the Sun round the Earth in the space of 365¼ days formed the measure of *the year*.

The motion of the Moon around the Earth gave the duration of the month, which is almost the twelfth part of the year.

The division of *the week* into *seven days* dates from the very creation of the world.

It is said in the Book of Genesis that God created the world in six days, and rested upon the seventh (that is to say, ceased to create); and God commanded that man should keep it holy, in commemoration of the repose which succeeded the work of creation.

M. Am. Sédillot, referring to the Bible story of the world's creation, says that it led to the conception of dividing the week into seven days. "The Greeks and the Romans, with whom seven was a sacred number, were acquainted, as Aulus Gellius testifies, with this division of time, but they did not employ it. The former counted by *the week* of ten days (*decades*), and the latter, in addition to the calends, ides, and nones, had their *week* of eight days (*ogdoades*)." *

Although the *days* spoken of in Genesis are not days in our meaning of the word, but undetermined periods of time, they nevertheless gave rise to the computation of the week which has been common to all nations. As Monsignor Meignan, in his excellent work on "*Le Monde et l'Homme primitif selon la Bible*," well says (page 12): "The week of seven days was in use all over Asia, more especially in Babylon. It was known to the Chinese, the Indians, and the Arabs. The Egyptians, it is true, counted by the decade; but they also were acquainted with our elementary division of time; and Dion Cassius states that this basis of the Roman calendar and the names of the planets applied to the days by the Romans were borrowed from the Egyptians. Tuch says that the week of seven days had its origin in a primordial principle which is universally known from the Ganges to the Nile. The legends of the Eastern peoples are only to be explained upon the assumption of a substratum of facts common to the whole human race; but it

* *Comptes rendus de la Académie des Sciences*, Dec. 9th, 1872.

is also certain that this primordial principle has been converted into a legend.

When the nations gave themselves up to idolatry, they conferred the names of the seven planets then known to their gods, consecrating *Monday* to the Moon, *Tuesday* to Mars, *Wednesday* to Mercury, *Thursday* to Jupiter, *Friday* to Venus, *Saturday* to Saturn, and *Sunday* to the Sun.

II.

The table indicating the division of time into days, weeks, months, and years, was called the *calendar*, from the calends which, with the Romans, fell upon the first day of each month.

The form and the arrangement of the calendar were not everywhere the same, and this has surrounded chronology and history with many difficulties.

With the Egyptians, the civil year consisted of 365 days; so that, taking no account of about six hours each year, the commencement of their year came round before the Earth had completed its revolution round the Sun, and so in course of time it began in the different seasons.

The Chaldæans took account of these four days, so as to make their year always begin at the same epoch; and this is why they had three years of 365 days, followed by one of 366 (Leap Year). Thus, after four times 365 or 1460 years, the Egyptians, losing a day every four years, in the solar year were 365 days a-head of the Chaldæans—that is to say, the year 1461 with them was only the year 1460 with the Chaldæans.

About 776 B.C., the Greeks began to count by *olympiads*, which was a period of four years named after the Olympic Games with the celebration of which it coincided.

The Roman year, under Romulus, consisted of ten months, of which March was the first, September the seventh, October the eighth, November the ninth, December the tenth—from the Latin words, *septem, octo, novem, decem.* Numa subsequently added the months of January and February, in reference to which addition Plutarch says: "Numa also changed the order of the months. March was the first of the year: he made it the third, putting in its place January, which, in the time of Romulus, was the eleventh. February, previously the twelfth and last, became the second. It is, however, generally believed that January and February were added by Numa, and that before his time the Roman year had only ten months, just as with some of the barbarians it has only three, or as with the Greeks, where the Arcadian year consists of four and the Arcananian year of six months. It is said that the Egyptian year formerly consisted of one and afterwards of four months. This is why that people, though inhabiting a very modern country, seem to reach back so far in history; they parade their infinite number of years, because each month counts as one." *

III.

From this epoch down to Julius Cæsar the Roman calendar gradually got into such confusion that the latter determined to have it reconstructed; and, by the advice of Sosigenes, an Egyptian astronomer, he instituted the Julian calendar in 45 B.C.

As with the Chaldæans, an extra day was interpolated

* Plutarch's *Life of Numa.*

every four years; and it was placed immediately after the sixth day before the calends of March, so as to make it the second sixth day (*bis sexta dies*), whence we have the name *bissextile* given to the Leap Years.

This correction was eventually insufficient; for, in counting the year at 365¼ days, it was made 11 min. 9 sec. too long. This mistake, imperceptible for a short time, produced a day too many every 134 years; so that by the year 1582 the spring equinox, which should have fallen on the 20th of March, came ten days earlier.

Pope Gregory XIII., to make the equinox come right, decreed the suppression of ten days; so that the day after the 4th of October that year was counted as the 15th.

It was also determined for the future to strike out three bissextile years every five centuries. Thus the years 1700 and 1800 were not bissextile, nor will 1900 be; but the year 2000 will be counted as bissextile. The *Gregorian* reform of the calendar was everywhere adopted, except by the Russians and Greeks, who adhere, even in the present time, to the *Julian* calendar, which explains why their year is twelve days behind ours. Thus, in writing to Russia, a letter is headed with the double date, as 8th/20th of July, which signifies that the 20th of July in England is the same as the 8th of July in Russia.

The Mexicans, for a people which were, so to speak, barbarian, possessed considerable astronomical knowledge, which they made use of for the purposes of their civil and religious life. They regulated the order of their two calendars, one of which, literally translated, means *reckoning of the Sun*, and the other *reckoning of the Moon*. The solar year was composed of 365 days, divided into 18 months of 20 days, plus 5 complementary days added on to the last month. It was represented in their paintings by a circle, in the centre of which was a figure of the Moon lighted by the Sun, and around it emblems of the 18 months (see fig. 58). In 1790

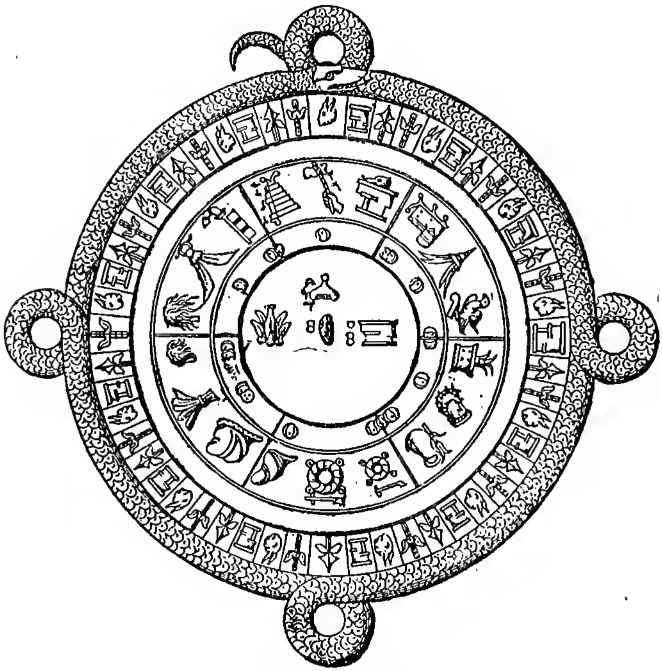

Fig. 58.—The Mexican year.

there was discovered amongst the foundations of Teocalli an enormous piece of trappean porphyry of a dark-grey colour and about 13 ft. in diameter, with a weight of 24,000 kilogrammes. It was covered with Mexican inscriptions relative to the religious feasts and the days when the sun was at its zenith. This relic has been well described by Humboldt as a *Mexican calendar* (see fig. 59, p. 351), and it has served to clear up several doubtful points, and to afford the present astronomers of that country some insight into the theories of their ancestors.

IV.

The *solar cycle* is a period of 28 years, at the end of which Sunday and the other days of the week recur in the same order and upon the same days of the month, because at the expiration of this time the Sun is nearly in the same sign and in the same degree of the ecliptic as it occupied 28 years before.

If the year was precisely composed of a certain number of weeks, the same dates of each month would continue to fall upon the same days of the week; but as the ordinary years comprise 52 weeks and 1 day, and the bissextile years 52 weeks and 2 days, it follows that no year begins or terminates with the same days of the week as the preceding one, and that, consequently, the same days of the week cannot fall upon the same dates of the month in two consecutive years.

But, after 28 years, the day in excess of 52 weeks in ordinary years, and the two days in excess of 52 weeks in bissextile years, make up a period of five weeks, when, as the 28th year is composed of an unfractional number of weeks, it follows that at the expiration of this period the years have the same days upon the same dates of the month.

The *golden number*, or *lunar cycle*, is a period of 19 years, at the expiration of which the lunations recur upon the same days of the month, and almost at the same hours. This is because 19 years, or 228 of our solar months, are within a fraction equal to 235 lunations. This period has been in usage since the most remote ages, and was termed *Saros* by the ancients (see Chapter I.).

These 19 years are indicated by the numbers 1, 2, 3, &c., up to 19, when they begin afresh. For instance, the golden number of 1865 being 4, this means that 4 years have elapsed since the recommencement of the lunar cycle.

This period was named the *golden number*, because, on its discovery by Meton, the Athenians were so pleased that they decreed that the calculation should be exhibited in letters of gold in the public resorts, for the use of the inhabitants.

It has, however, since been ascertained that the new moons do not recur exactly at the same hour every 19 years, as Meton supposed. The difference is about 1½ hours, which gives 1 day 30 minutes every 312 years. This is why it has been necessary to give up using the *golden number*, and to substitute the *epacts* (from the Greek, *to add on*) for ascertaining with precision the Moon's age.

V.

The *epact* is the age of the last Moon in a year at the beginning of the following year.

Thus, the number inscribed in the almanacs after the word *epact* indicates the number of days which have expired since the last new Moon of one year up to the 1st of January in the next year.

For instance, in 1852 the epact is 9, which shows that the last Moon of 1851 was 9 days old upon the 1st of January, 1852, and, consequently, that the new Moon began on the 21st of December previous.

As the epact is owing to the excess of the solar over the lunar year, to calculate it for any given year it is merely necessary to know the amount of excess, viz., 11 days.

To take an instance, in 1843 the solar and lunar years coincided, so the epact of this year was 0. In 1844 the epact was 11, representing the excess of the solar year.

In 1845 it was 22, or twice 11. In 1846 it was 33, or three times 11; but as the epact never exceeds 30, because 30 days make a month, 30, or an intercalated month, was subtracted from the number 33. This subtracted month was added to the year 1846, which was thus composed of 13 lunations, and the number 3 remained as the epact of 1846.

It is not very difficult to compile a calendar, for the main point consists in finding upon what day of the month Easter

Fig. 59.—The Mexican Calendar.

falls. This once ascertained, the movable feasts can be grouped around it in their order.

In A.D. 325 the Council of Nice ordered that Easter should be observed upon the first Sunday after the full Moon which follows the vernal equinox—that is to say, the full Moon which falls on or after the 21st of March.

To find this Sunday, we must trace, by means of the epact, upon what day of the month the new Moon of March will occur, and add to this date 14 days, which will give the day of the full Moon. If this day falls on or after the 21st, Easter will be on the following Sunday; but if the full Moon is before the 21st, then Easter will not be till the Sunday after the next full Moon.

This is why Easter varies from the 22nd of March, as it fell in 1848, to the 25th of April, as it will fall in 1886.

VI.

A somewhat important point will not be out of place here. M. J. Bertrand, a member of the French Academy of Sciences, put the following question to M. Jules Verne, the well-known traveller and writer:—

"A person starts from Paris on Thursday at noon, and proceeds to Brest, New York, San Francisco, Yeddo, &c. He returns to Paris after a journey of 24 hours at the rate of 15 degrees an hour. At each station he asks the time, and the invariable reply is, 'Noon.' He next asks the day of the week, and the uniform answer is, 'Thursday,' until he gets back to within a few miles of Paris, when he is told that it is Friday. Where does the transition take place¿ It must clearly be sudden. It will occur *at sea*, or in countries which do not know the names of the days in the week.

"But suppose a whole parallel upon the continent inhabited by civilised people, all speaking the same language and subject to the same laws, there will be two neighbours, one of whom will cry over the fence that separates their dwellings, 'It is now noon on Thursday,' while the other will answer, 'No, this is Friday.'

"But supposing them, on the other hand, to live in two adjoining villages near London, they will be agreed as to the dates in the calendar. Thus the puzzle would be at an end for the time; but it will spring up again in other places, and there will be no end to the changes in the dictionary ot the days of the week."

M. Verne's reply was: "It is true that going round the world travelling eastward a day is lost, and that going round the world travelling westward a day is gained—that is to say, the 24 hours occupied by the Sun in its apparent motion round the Earth. This result is so well ascertained, that the navy supplies the vessels going from Europe round the Cape of Good Hope with an extra day's rations, and gives one less to those which double Cape Horn. It is true also that, if there existed a parallel traversing regions all parts of which were inhabited, the inhabitants would be quite at variance in their reckonings. But such a parallel does not exist; nature has separated the chief nations by deserts and oceans. The transition from the day gained to that lost is effected imperceptibly. By an international convention, the arrangement of the corresponding days takes place at Manilla.* Captains of vessels alter the date in their log-book as they pass the eighteenth meridian." †

* This holds good of Paris, not London.

† *Les Mondes Scientifiques*, May 29th, 1873.

VII.

The *absolute time* is that which is measured by the daily motion of the Sun; its duration varies because the march of the Sun, or at least of the Earth, is unequal, alternately accelerated or slackened according as it approaches or recedes from the Sun. The *mean* or *equal time* is that measured by the mean speed of the Earth, or by an uniform motion, such as that of a clock. It is calculated upon the supposition that at the end of every twenty-four hours the Sun is exactly in the same meridian as it was the previous day. There are only four days in the year when the *mean* and the *absolute* time coincide—April 15th, June 15th, September 1st, and October 25th. The maximum *minus* difference is 18″·6; the maximum *plus* difference reaches 30″; but the balance is exactly equal at the end of the year, leaving out of consideration the planetary equations and the trifling secular variations.

The *precession of the equinoxes* is the imperceptible motion by which the equinoctial points are constantly shifting their position upon the ecliptic, moving westward, in an opposite direction to the order of the signs, so that the equinoxes arrive every year 20′ 25″ before the Earth is in conjunction with the Sun and the same star as in the same equinox of the previous year. This difference is the cause of the Sun's seeming to recede in the signs of the zodiac 1° in 72 years, and a whole sign or 30° in 2,156 years. Thus the Sun travels over the whole circle of the ecliptic in about 26,000 years. Since the constellations of the zodiac have received their names, the Sun has retrograded a whole sign, and though we still speak of its entering Aries in the month of March, we ought to substitute Pisces, and so with the other signs. The precession results from the unequal attraction which the Sun and the Moon exercise upon the various parts of the Earth, owing to its depression at the poles. Hipparchus first observed this phenomenon, which was explained by Newton.

The ancients designated under the name of *great year* a very long period, at the expiration of which all the planetary phenomena were supposed to recur in the same order and at the same epochs.

The astrologers declared that the occurrences on the Earth were connected with the celestial phenomena; so that it was thought of the first importance to define with precision the *great year,* all the historic events of which were to be reproduced *ad infinitum.* If such really had been the case, the history of one great year would have been the history of all future time.

Arago states that the chief ideas of the ancients concerning this period and its duration as estimated by various authors are as follows:—

The *great year,* also called the *perfect year,* the *year of the world,* was the time taken by the seven planets known to the ancients to return to the same relative positions.

Berosus says that the great year begins when the centres of the seven planets are in a straight line with each other.

Assimilating the great year to the ordinary years of civil life, Aristotle believed that the winter of this period corresponded to an *universal deluge,* and the summer to a *general conflagration.*

Berosus, on the other hand, maintained that winter set in when the line passing through the centre of the seven planets penetrated Capricorn, and summer when this same line passed through Cancer.

It does not seem as if the ancients were of one accord as to the nature of the phenomena leading up to the great year, some of them maintaining that there would be universal conflagrations, others universal inundations.

As to the duration of the year of the world, some authors estimate it at 6,670,000 years, while others, less venturesome, refuse to fix any exact time, believing that to be known to God alone. Cicero and Hesiod are amongst the latter, and Arago cites the following passage, from Hesiod :—

The duration of human life is	96	years.
The rook lives 9 times longer than man, or . . .	864	,,
The stag, 4 times longer than the rook, or . . .	3,456	,,
The crow, 3 times longer than the stag, or . . .	10,368	,,
The phœnix, 9 times longer than the crow, or . .	93,312	,,
The hamadryade, ten times longer than the phœnix, or.	933,120	,,

Thus the great year was a period entirely based upon astrological creeds, varying with the particular ideas of each astrologer. It exercised a great influence upon astronomy, compelling those who were desirous of ascertaining its duration to study with care the revolutions of the planets; and in this way it led to an advancement of science the progress of which ultimately destroyed the prestige of the astrologers.

CHAPTER XVII.

ASTROLOGY.

Dogmas of the astrologers—Curious facts—Natural astrology—Judicial astrology — Hippocrates — Virgil — Horace—Juvenal—Plutarch—Tacitus — Tiberius and Thrasyllus — Astrology in Mexico — Montezuma and the astrologers—Marsilius Ficinius—Pensa—Doctrines of the astrologers—Albert the Great—Thurneisen—Catherine de Medicis—Sensible advice given by Horace.

I.

Nothing is more curious to study than the origin of the various arts and sciences. It is astonishing to note the errors and prejudices even of the most strong-minded and talented of those who have begun to break fresh ground, and this should serve as a warning to pedants who believe that they are infallible. Astrology is derived from the Greek words *ἄστρον*, star, and *λόγος*, discourse. It is a science which consisted in reading or pretending to read the future in the stars. Astrology, therefore, had its origin in astronomy, which is, to use Kepler's expression, the well-conducted mother of a misbehaved daughter.

Both of these sciences were called into service by the professors of the healing art; and M. Franck, of the Institute, in a treatise upon mysticism and alchemy, remarks: "There can be no wonder that Paracelsus was less successful when he endeavoured to turn astronomy to the purposes of medicine, for while it is true, as a general principle, that all parts of the universe are connected with and react upon each other, it is impossible to define these connections, or to make any use of them, when they do not fall within direct observation or the laws of computation." *

There were two kinds of astrology: 1st, *natural astrology*, the object of which was to predict the return of the planets, the eclipses, the tides and the changes of time, the tempests, droughts, and inundations, as inferred from the data of astronomy; 2nd, *judicial astrology*, by which, as it was pretended, the destinies of individuals and nations could be foretold through the stars and their aspects. To the latter alone the word astrology, in its modern and derogatory sense, is applicable.

Most writers assert that this mysterious science originated in Chaldæa, whence it penetrated to Egypt, Greece, and Italy; others, again, attributed the invention of it to Shem, the son of Noah.

Herodotus relates that the Egyptians set the practice of dedicating each of the days and the months to some particular god, and that they were the first to judge of what a man's life would be by the constellation under which he was born.

II.

It was believed that the stars regulated the life and destiny of mankind, that each planet or constellation guided either to good or evil the being created under it, and that an astrologer, therefore, had only to know the hour and minute of any person's birth to determine the temperament, faculties, destiny, illnesses, and manner and even the date of his death.

Such was the belief, not only of the multitude, but even

* *Philosophie et Religion*, p. 79.

of those whose position and intelligence might have been expected to raise them above such prejudices.

Nearly all the ancients, including such men as Hippocrates, Virgil, and Horace, were believers in astrology.

Belus, King of Babylon, says: "I have read in the register of heaven all that will happen to you and your sons."

Juvenal writes: "The sign under which you are born is a very important one. Fortune may convert you from a spouter into a consul, from a consul into a spouter. What do such men as Ventidius or Tullius prove, unless it be the wondrous influence of a mysterious destiny, which at its pleasure raises a slave to a throne, a captive to a triumphal car? But so fortunate a man is rarer than a white crow." *

In the time of Varro, the contemporary of Cicero, and one of the most learned scholars of the day, there lived one Tarutius, a philosopher and mathematician who took a pleasure in dabbling in horoscopes, which he was reputed to observe with great skill.

Varro invited him to determine the day of the birth of Romulus, by a process of reasoning deduced from the known actions of his life, as is done in the solution of geometrical problems. The same theory which, with a given birth, forecasts a man's life, should, he said, be able, with a given life, to discover the moment of his birth.

Plutarch, in his *Life of Romulus*, tells us that "Tarutius complied with Varro's request. After making a very careful study and comparison of both the adventures of Romulus, the duration of his life, the manner of his death, and the rest, he unhesitatingly announced that Romulus was conceived in the first year of the second Olympiad, upon the 23rd of the Egyptian month Chœac, at the third hour of

* Juvenal, Satire vii.

the day, during a total eclipse of the Sun; and he added that Romulus was born on the 21st of the month Thoth, about sunrise, and that he founded Rome upon the 9th of the month Pharmonthi, between the second and third hour.'

Fig. 60.—The Parcæ, or Fates, and Prometheus, after an ancient bas-relief.

. . . "It is, in fact," Plutarch goes on to say, "the opinion of mathematicians that the fortunes of a city, like those of an individual, have their appointed times, which are governed by the position of the stars at the first instant of its foundation." But, as Plutarch indicates in a subsequent passage, the belief in astrology was not universal in those days.

III.

Tacitus mentions that Tiberius had a great fondness for astrology. He says: "I must not omit to mention a prediction which Tiberius made concerning Servius Galba, then consul, whom he had summoned to Capreæ. After sounding him on various subjects, he added in Greek: 'And thou too, Galba, wilt one day taste the sweets of empire,' thus foretelling the latter's long-delayed and ephemeral reign. He had learnt astrology at Rhodes from Thrasyllus, whose skill he had put to the following test:—When Tiberius consulted an astrologer, he repaired to the highest storey in his palace, and took as his only confidant an ignorant but lusty freedman, who conducted by steep and precipitous paths (the palace being perched upon a rock) the man whose skill Cæsar desired to test. On his return, the freedman was to have precipitated him into the sea, if he had been suspected of indiscretion or trickery. Thrasyllus, conducted in this way to the palace, had impressed Tiberius by his replies, and by his disclosing to the latter prospects of future empire. Cæsar asked him if he had drawn his own horoscope, and what sign he was then under. Thrasyllus then proceeded to examine the position and the distance of the stars, which done, he hesitated, and, after a second study, began to tremble, exclaiming: 'The day is evil, my last hour is at hand.' Tiberius thereupon embraced him, and, felicitating him upon having escaped a danger by foreseeing it, accepted all his predictions as oracles, and admitted him into the number of his most intimate friends." *

When Tiberius decided to leave Rome for Campania, the astrologers made various forecasts relative to the journey. "Those who were able to read in the sky said that at the moment of Cæsar's leaving Rome the position of the stars indicated that he would never return there; and this was fatal to many of them; for, in drawing the horoscope and predicting from it his early decease, they had no conception of his singular determination, and of the voluntary exile which was to keep him eleven years absent. This showed how indefinite is the limit which separates truth from falsehood and light from darkness. In their announcement

* Tacitus, *The Annals*, Book vi.

that Tiberius would never re-enter Rome the astrologers were right; but in all other respects they were wrong, for he lived to an extreme old age.*

Astrology was in great repute amongst the Mexicans, and every event was influenced by the hieroglyphics of the day, demi-decade, or year. Hence the conception of coupling together the signs, and of creating those purely fantastic bodies which we find so frequently repeated in the astrological paintings extant, of which a rough idea may be gathered from figs. 59, 60, and 61, representing the calendar, the year, and the signs of their days.

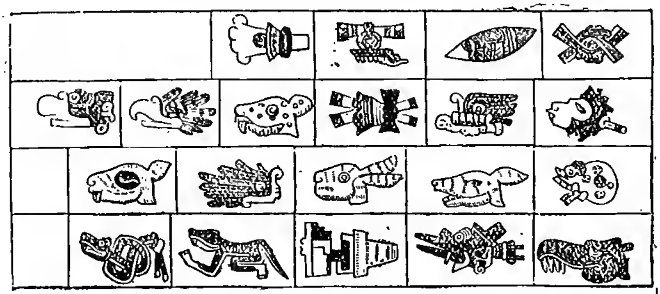

Fig. 61.—Signs of the days in the Mexican Calendar.

The apparition of a comet in the beginning of the sixteenth century created great consternation in Mexico, the multitude looking upon it as a presage of coming disaster. The enemies of Montezuma, who was then on the throne, said that it was a forerunner of his fall; and, to dispel such alarm, which he felt might be dangerous, the emperor ordered his astrologer to explain the origin of this apparition. The latter, who knew no more about it than the rest of his compatriots, interpreted it in the same sense, and was of course, as usual in those days, put to death.

* Tacitus, *The Annals*, Book iv.

It is astonishing to remark with what obstinacy the ideas of the astrologers were adhered to, no matter how often they proved false. The bishops and other ecclesiastics of the highest rank, the most celebrated philosophers and doctors of medicine, drew the horoscope, and lectures were delivered upon this subject at the university courses.

Marsilius Ficinus, in his "Treatise upon the Prolongation of Life," which was published during the last century, recommends all prudent persons to consult an astrologer every seven years, so as to be warned against the dangers to which they might be subject during the coming seven, and above all to esteem and make use of the remedies of the Three Kings—gold, myrrh, and frankincense. M. Pensa dedicated, in 1720, to the Council of Leipsic, a book entitled "De Propagandâ Vitâ, Aureus Libellus," in which he recommended the members, as essential to their welfare, to learn with care which constellations were favourable and which the reverse, and to be on their guard every seventh year, when Saturn, a very malignant planet, predominated.

IV.

The doctrine of the astrologers was, to put it into a small compass, as follows:—

The seven principal planets and the twelve constellations more especially influence human destiny and the events of the world. The seven planets were: the Sun, the Moon, Venus, Jupiter, Mars, Mercury, and Saturn. The Sun presides over the head, the Moon the right arm and Venus the left, Jupiter the stomach, Mars the genital organs, Mercury the right foot, and Saturn the left.

In the constellations, Aries governs the head, Taurus the neck, Gemini the arms and shoulders, Cancer the chest and heart, Leo the stomach, Virgo the abdomen, Libra the loins, &c., Scorpio the genital organs, Sagittarius the thighs, Capricorn the knees, Aquarius the legs, Pisces the feet.

Not only individuals, but even states, towns, and villages, were placed beneath the influence of the constellations. In the course of the sixteenth century the German astrologers declared Frankfort-on-the-Maine to be under the influence of Aries, Wurzburg of Taurus, Nuremberg of Gemini, Magdeburg of Cancer, Ulm of Leo, Heidelberg of Virgo, Vienna of Libra, Munich of Scorpio, Stuttgardt of Sagittarius, Augsburg of Capricorn, Ingolstadt of Aquarius, and Ratisbon of Pisces.

Albert the Great assigned the following influences to the planets:—

Saturn was supposed to preside over life, change, sciences, and buildings;

Jupiter over honour, desires, wealth, and cleanliness of garments;

Mars over war, prisons, marriages, and feuds;

The Sun over hope, happiness, profit, and inheritances;

Venus over friendship and love;

Mercury over illness, debt, commerce, and fear;

The Moon over wounds, dreams, and theft.

Each of these planets was represented by a particular day in the week, a colour, a metal, &c.

The Sun presided over Sunday; the Moon, Monday; Mars, Tuesday; Mercury, Wednesday; Jupiter, Thursday; Venus, Friday; Saturn, Saturday.

The Sun represented yellow; the Moon, white; Venus, green; Mars, red; Jupiter, blue; Saturn, black; and Mercury the variegated colours.

The Sun was predominant over gold, the Moon over silver, Venus over tin, Mars over iron, Jupiter over brass, Saturn over lead, Mercury over quicksilver.

The Sun was considered beneficent and favourable; Saturn, dreary, morose, and cold; Jupiter, temperate and benignant; Mars, ardent; Venus, beneficent and fruitful; Mercury, inconstant; the Moon, melancholy.

Of the constellations, Aries, Leo, and Sagittarius are hot, dry, and ardent; Taurus, Virgo, and Capricorn, oppressive, cold, and dry; Gemini, Libra, and Aquarius, light, hot, and damp; Cancer, Scorpio, and Pisces, damp, enervating and cold.

V.

The horoscope is drawn by studying the combinations of these influences, and examining with care how the planets meet the constellations. For instance, if Mars meets Aries at the moment of birth, the prognostic is courage, pride, and long life.

Mars, according to the astrologers, augments the influence of the constellations with which it coincides, adding valour and strength.

Saturn, the symbol of evil influences, counteracts the good ones.

Venus augments the good and diminishes the evil ones.

Mercury augments or diminishes the original influences, according as he encounters a lucky or unlucky sign of the zodiac.

The astrologers also drew prognostics from the auroræ boreales, the comets, &c.

For the horoscope to be trustworthy, it was deemed necessary to commence operations at the very moment of a child's birth, or at the very beginning of any matter of which it was sought to know the sequel.

The celebrated Thurneisen, a man of really great genius, resided during the eighteenth century at the Electoral Court of Berlin, where he was at once physician, chemist, drawer of horoscopes, compiler of almanacs, printer, and librarian.

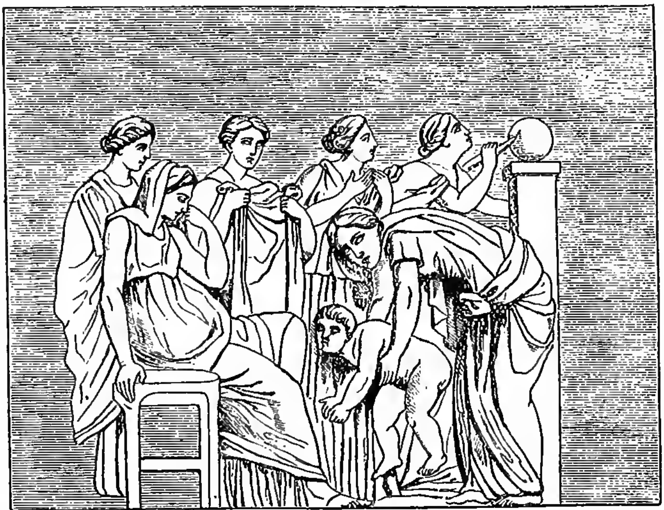

Fig. 62.—Birth and horoscope of a child, after a Greek bas-relief.

His reputation as an astrologer was so extensive, that scarcely a child was born in any wealthy family of Germany, Poland, Hungary, Denmark, or even in England, without the precise moment of its birth being communicated to him. Sometimes as many as ten or twelve messages of this kind reached him at the same time, and he was at last so overcharged with work, that he was compelled to hire assistants.

Whole volumes of such applications, inclusive of letters from Queen Elizabeth of Prussia, are still to be seen in the Library of Berlin. Thurneisen also compiled an annual almanac of astronomy, in which he indicated in a few sentences, or with certain signs, not only the general character of the year, but also the principal occurrences and the temperature for each day.

He only gave these explanations, it is true, the year after; still it is certain that, either out of complaisance or for some other motive, he several times communicated his observations beforehand.

His almanac had an enormous success for twenty years, and enabled him, together with other sources of revenue, to amass a fortune of nearly half a million florins.

VI.

How could an art, while acknowledging that life had its impassable limits, offer a secret for prolonging it?

The secret was as follows:—Just as every man is subject to the influence of a certain constellation, all the other bodies of the animal or vegetable kingdom, and even entire countries and houses, had their separate constellations to which they were subject.

There was, more especially, a complete relation between the planets and the metals.

Thus, when a man knew from what constellation his misfortune or malady arose, he had only to use the food and drink and inhabit a region placed under the influence of the opposite planets. Thus was originated a new system of dietetics, very different, no doubt, from that of the Greeks.

If a particular day, owing to the constellation in which it happened to be, foreboded some kind of accident or illness, the person threatened repaired to a place which was under a favourable constellation, or else took food and medicine which had grown under such favourable constellation.

It was in the same way that people hoped to preserve their lives by the wearing of amulets and talismans.

The metals and the planets being intimately related, it was thought that by carrying a talisman composed of metals run together, moulded, and engraved under and in harmony with certain constellations, the wearer would be penetrated with all the power and protection of this planet.

Thus there were talismans against the maladies due to the influence, not of one planet only, but of all; and there were others which, by the alloy of certain metals—a peculiar process of fusion—were reputed to destroy the influence of the malignant constellation which had presided over a man's birth, to make him prosperous in business, marriage, &c.

If the talisman had upon it the impress of Mars in the sign of Scorpio, and if they had been fused under this constellation, they rendered the wearer invulnerable and certain of success in battle.

The French historians observe that judicial astrology was so much in vogue during the time of Catherine de Medicis, that no important undertaking was begun without first consulting the stars; and during the reigns of Henri III. and Henri IV. in particular, the astrologers were looked upon as interpreters of the Divine Will.

I will terminate this chapter with a passage from Horace which shows that the Roman poet was fully alive to the ridiculous pretensions of the astrologers; for in Book III., Ode 29, he says: "The wisdom of the Supreme has covered the future with a veil, and he who would pierce the cloud exposes himself to the derision of Jupiter."

Again, in his ode to Leuconoë: "Believe me, it is better for us not to inquire which will die first. Let us have nothing to do with sorcery, and, whatever happens, let us await with submission the decrees of Jupiter. Whether he intends to let us live yet some more winters, or whether we have seen for the last time the Tuscan sea dashing against the rocky shore, let us be wise, and filter the wine. Let us regulate our hope according to the shortness of life, and be resigned. Take to-day, which will perhaps have no morrow. The moment during which I am now speaking is already far behind us."*

* *Odes* of Horace, Book i. Ode ii.

CHAPTER XVIII.

THE HARMONY OF ASTRONOMY WITH THE SPIRIT OF RELIGION IN ANTIQUITY.

I.

My work would be incomplete unless I attempted to show the connection—the scientific connection, I may almost say—which in ancient times existed between astronomy and religious knowledge.

The chief occupation of the Chaldæan priests was the study of astronomy. In India, the guardians of the sanctuary were also the guardians of astronomy; in China, the functions of astronomer were incorporated with those of chief director of religious ceremonies; in Egypt, the astronomers were also priests, and used the flat roofs of the temples as observatories.

In fine, throughout the whole of antiquity, astronomy was always looked upon as the religious science *par excellence* (see Chapter I.).

The bond which thus united religion and astronomical science is a forced consequence of man's nature, and of the necessary ideas which form, so to speak, part of his existence. This is easy of demonstration.

When man attains the age of reason, and can comprehend what is taking place around him, he finds himself in possession of a certain number of ideas common to everybody else—ideas which arise spontaneously in the minds of all men from the very fact of their being alive. I refer to the ideas of time, cause, space, &c. (which is why they are called *necessary ideas*), and to the elementary principles arising in connection with them, which are called *axioms*.

Herein the idea of cause plays the principal part. When an infant begins to speak, it does not ask if such and such a thing has a cause, but what the cause is. "Who made that pretty thing? What is that pretty thing for?" The child, of course, does not use the word cause, but from instinct it expresses its desire to know *why* such and such a thing is. The older he grows, the more marked does this idea become; and if, when he is capable of reasoning, he was told that a certain fact had no cause, he would think that the person who told him so was in joke, or that he was making light of his intelligence.

This idea of cause is inseparable from the very essence of man. It is natural to us all; it is innate in the intelligence of every man from the very fact of his existence.

II.

This idea of cause has also an essential character which must be pointed out.

Instinctively, naturally, the human mind forms an idea of the cause analogous and proportionate to the effect by which it is revealed, and it inspires him with different sentiments, according to the effects which he attributes to it.

A powerful but indiscriminate cause may excite surprise, awe, or terror; but it does not command either admiration or affection.

A great power, working with intelligent order, imposes a feeling of admiration.

A great power, combining in its elements intelligence, wisdom, and goodness, inspires at once wonder, veneration, and affection.

Thus, an effect which manifests at once power, intelligence, wisdom, and goodness, creates the idea of a cause both powerful, intelligent, wise, and good, and inspires for this cause a feeling of respect, veneration, and affection.

The conduct of all men not influenced by contrary passions is a proof of it.

Moreover, each individual has but to question his own self to be persuaded that this is the law of his soul; and though he may break this law in his course of conduct, it none the less exists.

The proof is also to be found in the general terms of language which men employ.

A man is called powerful because he has done a certain act; clever, because he has succeeded in some skilful undertaking; yet, before according him our attachment, we require to know whether he is of a good or an evil disposition; for if the latter, he might do us much harm. Another man has become the benefactor of his country by the use of his great abilities, his wisdom, and his goodness, which attains the proportions of self-devotion; such a man inspires, not only respect, but veneration and affection. And so we instinctively assign to each a rank proportionate to his merits.

This is the history of the whole human race, whenever conscience is under no restraint.

III.

Again, the aspect of the universe at large, of the mighty ocean, of the pure, calm azure of the firmament; the motions of the atmosphere, whether in the blast of the dark forests or in the perfumed murmur of the gentle breeze; the rising and setting of the planets, with their inseparable and magnificent *cortége*, their unchanging and harmonious motions in the deep vault of heaven; all these magnificent phenomena, revealed to us by the contemplation of the universe, and belonging more or less to the domain of astronomy, exceed in their grandeur anything that the human mind can conceive. They instinctively give rise to the idea of infinite power, wisdom, and goodness, and reveal to us a cause infinitely powerful, intelligent, wise, and good; and that cause is God.

It is not surprising, therefore, that the science, the study of which is indissolubly connected with the contemplation of the universe, which reveals God himself, has been looked upon as an act of religion, as a manner of prayer.

In our day, the special study of astronomy is no longer limited to a general contemplation of the universe; its votaries are absorbed in examining the constitution of a planet, like the natural philosopher studying the chemical composition of some body, or they are engaged in transcendent abstract calculations; which being the case, it is easy to understand how it has lost much of its religious character.

IV.

All the ancients, as a rule, looked upon the universe as the very expression and demonstration of God.

Cicero, uttering at once his own opinion and that of the earlier philosophers, says:—

"The fourth argument of Cleanthes (to prove that men have an idea of the existence of gods) is much the strongest, viz., the regulated motion of the sky, and the distinct features, the variety, the beauty, and the disposition of the Sun, the Moon, and the other planets. It is only necessary to look at them to see that they are not the results of chance. Just as, when we visit a vast and well-ordered establishment, the presence of perfect discipline and reasoned economy reveal the presence of a very capable manager, so much the more must the prodigious number of stars revolving from the most remote epoch with unfailing regularity in their courses, convince us that they are governed by a master-mind." *

Aristotle well remarks that, "If we suppose men that had always lived underground in sumptuously decorated dwellings, heard of the existence of gods, and were suddenly projected upon the Earth by an upheaving of the lower regions which they inhabited, and there brought face to face with the marvels of nature, is it possible to doubt but that they would at once attribute them to the gods of whom they had heard?"

Man soon comes to disregard the most marvellous objects when his mind is pre-occupied and his attention concentrated upon matters of special and more immediate interest to himself.

To quote Cicero a second time: "If we emerged from everlasting darkness, and saw light for the first time, how beautiful the heavens would appear to us! But because we are accustomed to it, it ceases to impress us, and we travel far afield in search of principles which are before our very eyes. . . . Is it reasonable in man to attribute, not to a preconceived cause, but to chance, the fixed motions of the sky, the regular course of the stars, all so connected

* Cicero's *De Naturâ*, Book ii., n. 15, 95, 96, 97.

together, so well proportioned, and conducted upon such symmetrical bases, that our reason is unable to fathom them? When we see machines, such as a sphere or a clock, regulated by artificial motion, we know that they are creations of the human intelligence. Why, then, should we doubt that the world is governed by an intelligence not merely human, but divine?"

The French peasants re-echo, in a rough untutored form, the words of Cicero; for during the Reign of Terror, on a member of the Convention telling a Vendean peasant that the church-steeples should be demolished to sweep away the last traces of their religious belief, the latter replied, "Well, you may do that; but you can't abolish our stars, and we see them from a much greater distance." *

V.

I now come to a very singular argument used by those astronomers who deny the existence of a Supreme God. I say strange, for the argument tells against those who use it.

They say: "If science has succeeded in showing that the whole universe is regulated by fixed laws, that each star has its own unchanging course, and that the unbroken harmony and order which reign in immensity, opened in all its recesses to the astronomer who is armed with powerful instruments, are but the rigorous outcome of these laws, a Creator is no longer necessary, and the worlds are entirely independent of him."

Such a process of reasoning is equivalent to saying, "This chronometer, which never varies, and each motion of which

* M. X. Marmier's Discourse in the French Academy.

is like an echo of the motion of the stars which indicate the time, does not require the maker to come and regulate its motions from day to day: therefore it goes of itself. But this watch, always out of order, is incessantly under repair, so we see that it did not create itself. This is what such a pitiful train of reasoning leads up to, and I must almost ask the reader's pardon for exposing it in all its nakedness.

It is more than a century since Lalande had the hardihood to exclaim, "I have examined the whole expanse of the heavens, and I can find no trace of God." And this because he had observed in every direction the traces of infinite wisdom!

If the universe had been so imperfect that the Almighty was incessantly occupied in replacing the stars in their courses, His existence would not be called into question; but because His work bears the impress of infinite wisdom, we adduce that very fact as a reason for contesting the existence of the Maker! Is it possible to find a more striking instance of unreason?

Should we not rather feel that the further the study of the universe is carried, the more convincing are the proofs of the grandeur and the perfection, not only of it, but of Him who created it?

VI.

Man naturally and instinctively attributes a cause to each effect, and this imperious moral instinct has never been found wrong, when it has been possible to trace back from the effect to the cause. It is the same imperious instinct, the same law of the soul, which makes him attribute an infinite cause to the universe. Therefore, if we stop half way, we are wanting in logic; we break the chain of reasoning, just as if we refused to recognise a cause to a series of phenomena.

This is so true, that to tell a man who possesses all his reasoning faculties, and who is unbiassed by any external influences, that the world was created of itself, that there is no sovereign cause—in a word, no god—is to revolt his common sense. It is equivalent to asking him to believe that there is such a thing as an effect without a cause. It is even worse, for not only do his mental faculties resent such a suggestion, but he will feel horrified at such a patent contradiction of moral certainties.

Thus, to deny the sovereign cause—to deny God—is to run counter to logic, to the laws of intelligence, and of feeling. I will go even further, and assert that it is contrary to the principles of science, for to admit the possibility of effect without cause is to abandon anything in the shape of scientific method, and I repeat that the law of causation ascends by successive links up to the supreme cause. To stop half-way is to break that chain of reasoning which is the consequence of the laws of the soul.

Those who run counter to the rules of logic and science in this way argue: But how do you explain the Supreme Cause?

This is a different question; but whether or not we can explain the Supreme Cause, the law of our soul none the less exists, and no reasoning should induce us to violate it.

This also holds true of the objections which may be derived from special facts against the infinite wisdom, justice, and goodness of which the general laws of the universe bear the imprint. For these objections to possess any force, those who urge them would first need to have at their fingers' ends the past, present, and future history of the worlds, about which we know so little that no argument can be based upon it.

VII.

Nevertheless, the thought that men of high intellect have come to doubt the existence of a Supreme Cause, creates a very uneasy feeling in many minds. Those who are thus painfully affected in their habitual beliefs say: These savants must have discovered some very terrible secrets which they do not dare to reveal, and which prove to them that God is a myth. Otherwise, how is it that, with an intellect greater and more fully developed than mine, they do not feel as I do, and adore with even greater fervency the Maker of all the marvels which they have laid bare? This is a natural course of reasoning; but, on reflection, the facts which seem so strange to them admit of a simple explanation. Those who deny God have not discovered any terrible secrets; for everything in science, more especially in the advanced sciences, tends to augment the knowledge of causes and laws, and consequently tends to reveal to us a Supreme Cause, and make us appreciate still more highly His greatness and wisdom.

How can they who thus stop short in their train of reasoning assert that the universe proves nothing—that the Supreme Cause does not exist? It is clear that they cannot make such a statement without being false to themselves and to those whom they address, for they have no evidence to offer in its support.

And if they say so in the name of science, they take that name in vain; for science has never shown that there can be an effect without a cause. On the contrary, the farther it progresses, the more striking is its demonstration of the dependency of effect upon cause, the nearer does it approach to the laws which regulate their connexion, and so towards a knowledge of the Supreme Cause.

All that man can do in good faith in this matter is to doubt. He may reach this sad condition either by allowing his intellectual faculties to take a false direction, which deprives them of their spontaneity, and so of their liberty (which comes of dwelling too much on exclusive studies) or by the habitual current of his ideas. With some natures, passion also will so trouble and prejudice the mind, that it cannot perceive matters within the range of an ordinary intellect.

Thus a man may, with the best intentions, become the victim of involuntary illusions; without losing his reason, he may lose the notions of common sense in many matters, and his faculties will become warped in a way incredible to those who have not studied the chapter which is at once physiological and psychological. The mind constantly fixed upon one thing, losing its spontaneity, will account for it. Or perhaps the following paragraph will set the matter in a clearer light.

It is our common sense and reasoning power that reveal to us the Supreme Cause and the great truths of the moral world. But the widest development of the intellect and all the erudition in the world add nothing to the evidence of common sense and the rectitude of judgment; on the contrary, there is a danger, as the intellect develops, of common sense becoming contracted and unable to seize the notions which belong to its domain, and upon which all human knowledge is based.

This may be remarked every day and every hour in matters far less important than the great truths of which I am speaking. We encounter every day rough uneducated people with an amount of common sense and a rectitude of judgment greater than is possessed by many persons of far higher intellectual attainments. It must be evident to all those who study the question, that the great truths upon which are based the first principles of morality come within the domain of common sense; not within that of science strictly speaking, which, far from helping to demonstrate them, often serves to make their study more difficult.

VIII.

There is another observation of some importance which I must not omit.

Man possesses not only the faculty of knowledge, but he is endowed with sentiment, that is to say, the faculty of being moved by anything grand or beautiful, of *feeling* the expression of it in his inner soul, and of forming a disinterested attachment to it.

But all men do not possess these two faculties in the same degree; and it is, indeed, important to bear in mind that some men have great intellect, and even a large fund of sensibility and susceptibility, without possessing a shadow of sentiment. They are unable to appreciate or take in anything which does not appeal to their intellect; the splendours of the universe make no impression upon them, and if it unfortunately happens that their common sense becomes obscured by the concentration of their intellect upon a single object, or by the influence of some particular passion, their apprehension of moral facts seems to be entirely deadened. They are devoid of the sentiment of feeling which will often serve to replace a deficiency of common sense. Intellect shows us what exists and what it is our duty to do; with sentiment we feel all this without being able to give the reason why. We may say with Pascal: "For the heart has its reasons, of which judgment so-called knows nothing;" or with Vauvenargues, in his "Réflexions et Maximes": "Judgment and sentiment, each in their turn replacing one another, give good counsel." Those who are endowed with intellect alone possess but the half of a human soul.

To those endowed with a great amount of sentiment, the aspect of the universe reveals the Supreme Cause, not only to their intelligence as a logical consequence, but it also causes them to feel, in spite of themselves it may sometimes be, the existence and the presence of the invisible Cause.

This is why those more refined and elevated natures in which the heart and the intellect are alike far above the level have never questioned for an instant the existence of a God; they may have been unable to admit the truth of some particular religion or dogma, but they have never felt any doubt as to the existence of the Supreme Cause, infinitely powerful, wise, and good. Moreover, all truly great men—all those whose names are illustrious in the world's annals as the benefactors of humanity—have been believers in God.

It seems to me, therefore, that all these considerations tend to demonstrate that the bond which in ancient times united astronomical science and religion has its origin in the very nature of man and his necessary relations with the universe; that the idea of causation leads up to the recognition of the Supreme Being as a rigorous and inevitable outcome of the laws of the mind; and that the universe, being His natural expression, renders Him present to our sentiment.

Fig. 63.—Atlas (from the Farnese Collection).

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